DEVELOPMENT OF AN ECONOMIC MODEL TO ASSESS THE FEASIBILITY OF THE NUCLEAR INDUSTRY TO PRODUCE, HANDLE, AND OPERATE COMMERCIAL FUEL WITH ENRICHMENTS GREATER THAN 5-WT% U^{235} FOR PWRS IN THE UNITED STATES

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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This work is dedicated to my wife, Renee.

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The nuclear power industry in the United States is currently limited to 5-wt% U^{235} fuel. Increasing this enrichment limit would enable utilities to decrease the number of spent fuel assemblies, allow upgrades in reactor power, have more flexibility in fuel cycle lengths, and allow for the development of advanced fuel designs. Any increase in fuel enrichments requires an extensive analysis of the entire fuel cycle including enriching, conversion, manufacturing, shipping, and storage of enriched fuel. The cost of the detailed analysis, licensing, and modifications to existing facilities or the construction of new facilities appears to justify the use of higher enriched fuel. The purpose of this study was to develop an economic model to determine the feasibility of using greater than 5-wt% U^{235} commercial fuel. The study focused on evaluating typical fuel-processing operations to establish limits on current facilities and cost penalties for the required modifications for processing, fabricating, shipping, and storage of higher enriched fuel

The results of this study indicate that incentive to increase enrichments depended on the cycle length utilized. For reactors on an 18-month cycle there was little incentive to increase enrichments. However, potentially millions of dollars per year could be saved by reactors on a 24-month cycle if they increased enrichments up to 6.5-wt% U^{235}. Larger incentives occurred for reactors using longer cycles.

The fuel purchase interest rate was the dominant factor in determining the cost savings in using higher than 5.0-wt% fuel. Increases in interest rates alone could result in significant losses if higher enrichments were used. The other dominate factor affecting savings is the separative work charge. However this cost appears to be stable with new facilities planned. Thus, although interest rates are volatile, the potential gain appears to outweigh any loss that could be seen by increased enrichments beyond the current licensing limit of 5-wt% U^{235} for plants on a 24-month or longer cycle.

CHAPTER 1
INTRODUCTION

Motivation and Objective

In the United States there is a strong nuclear industry incentive for increasing fuel reload enrichments for several reasons. First and most importantly, the industry, with the 5-wt% limit on fuel enrichments, is finding current fuel cycle flexibility greatly restricted. The upgrading of reactor power at nearly every plant is creating a demand for even higher enrichments to maintain the two year cycle length. Fuel cycles with higher burnups are desirable in order to decrease energy costs and the number of spent fuel assemblies. Higher burnups require higher enrichments than the currently licensed maximum of 5 wt% U^{235}. Whether the industry is able to move to increased fuel enrichments beyond 5-wt% depends to the greatest extent on the cost of required equipment and process modifications to the current infrastructure to meet licensing requirements versus the economic benefits of the increased burnup and cycle length. Additionally, new incentives such as a reduced waste charge for higher burnups would also encourage higher enrichments to become a reality. An economic penalty associated with processing higher enrichments will prevent reactors from going to higher enriched fuels. There is an industry concern that the required modifications and licensing costs of higher enrichment may negate any fuel cycle advantages. This study is intended to address those questions.

The factors which have both economic and noneconomic incentives to increase enrichments are 1) fewer licensing submittals as a result of fewer refuelings due to the longer cycle lengths that can be achieved from higher enriched fuels, 2) increase in availability and capacity factor due to longer cycles, 3) upgrades in reactor power, 4) reduced need for high cost of replacement power during refueling outages, 5) lower radiation exposure to operating personnel, 6) a decrease in the number of spent nuclear fuel assemblies, and 7) a decrease in separative-work-unit (SWU) loss resulting from disposition of weapons-grade uranium, and 8) improved fuel designs. Additionally, as a result of new and improved reactor designs being proposed as part of the Nuclear Engineering Education Research (NEER) and Nuclear Energy Research Initiative (NERI) research programs to improve reactor safety and performance, such as International Reactor Innovative and Secure (IRIS) and Particle-Bed Gas-Cooled Fast Reactor (PB-GCFR), new core and fuel designs requiring higher enrichments are being proposed.

Any move by industry to increase enrichments will depend on the cost of changing the front end of the fuel cycle to higher enrichments and its effects on the back end of the fuel cycle. The licensing process for higher enrichments for fuel processing, transport, and handling will require sufficient criticality data in the higher enrichment range to satisfy the Nuclear Regulatory Commission of the accuracy of the codes being used to qualify the process. Some economic disincentives for going to increased enrichments would be additional costs from (1) required changes to the manufacturing process to ensure criticality safety, resulting in smaller batches, (2) a requirement for more poisons in the processing and handling equipment, (3) excessive licensing requirements for higher enriched fuel, (4) requirements for extensive modifications to fuel manufacturing

facilities, shipping containers, and utility fuel storage racks to receive, store, and dispose of the higher enrichment fuel, and (5) licensing requirements for extensive criticality test data. For increased enrichments to be economically viable, the penalty for the processing, transporting, handling, and storage must be relatively small compared to current costs. The primary purpose of this research is to develop a model of the fuel cycle and examine the feasibility and the cost impact of increasing fuel enrichments in the range of 5 to 10 wt% U^{235}.

Previous Research

Currently there are only a few criticality experiments in the five to ten weight percent enriched range [1]. There is one experimental set from Great Britain with seven percent enriched uranium as UO_2 rods, several solution systems documented by the Japanese and some US metal experiments starting at nine percent enriched and higher. There are five Russian UO_2 light water reactor experiments. The first experiment, LEU-COMP-THERM-022, was titled "Uniform Water-Moderated Hexagonally Pitched Lattices of Rods with U(10%)O_2 Fuel" and composed of seven critical experiments for uniform fully flooded hexagonal lattices with pitch values of 0.7, 0.8, 1.0, 1.22, 1.83, and 1.852 cm. The second experiment, LEU-COMP-023, was titled "Partially Flooded Uniform Lattices of Rods with U(10%)O_2 Fuel", and composed of six critical experiments for different levels of water in the active core. The pitch value of the lattice was 1.4 cm. Water levels were varied from 22.58 cm to 64.58 cm as the number of rods was decreased. The third experiment, LEU-COMP-024, was titled "Water Moderated Square-Pitched Uniform Lattices of Rods with U(10%)O_2 Fuel" and composed of two critical experiments for two square-pitched lattices of fuel rods. The pitch values of the lattices were 0.62 and 0.8768

cm The fourth experiment, LEU-COMP-025, was titled "Water-Moderated Hexagonally Pitched Lattices of U(7 5%)O2 Stainless Steel-Clad Fuel Rods" and composed of four fully flooded critical configurations with hexagonal lattices with pitch values of 7, 8, 10, and 12 2 mm The fifth experiment, LEU-COMP-032, was titled "Uniform Water-Moderated Lattices of Rods with U(10%)O2 Fuel in Range From 20 °C to 274 °C" and composed of nine critical experiments for uniform fully flooded hexagonal lattices with pitch values of 0 7, 1 4 and 1 852 cm at three different temperatures ranging from 20 C to 274 C for each lattice All experiments were brought to a k_{eff} value of 1 000 The experiments were modeled in MCNP4a and ran 500 generations, skipping the 1st 50, 1000 neutrons per generation for a total of 450,000 histories. The results of the MCNP models of the critical experiments with one standard deviation as well as the uncertainty of the benchmark models are given in the following tables

Table 1 1 Results of MCNP4a sample calculations from LEU-COMP-THERM-022 [1]

case no	k_{eff}	σ	Uncertainty of the Benchmark Model k_{eff}
1	1 0011	0 0011	0 0046
2	1 0056	0 0011	0 0046
3	1 0073	0 0012	0 0036
4	1 0082	0 0012	0 0037
5	1 0048	0 0011	0 0038
6	1 0030	0 0010	0.0048
7	1 0047	0 0009	0 0046

Table 1-2 Results of MCNP4a sample calculations from LEU-COMP-THERM-023 [1]

case no.	k_{eff}	σ	Uncertainty of the Benchmark Model k_{eff}
1	0.9972	0.0011	0.0044
2	0.9995	0.0011	0.0044
3	1.0013	0.0011	0.0044
4	1.0017	0.0011	0.0044
5	1.0029	0.0011	0.0044
6	1.0031	0.0010	0.0044

Table 1-3 Results of MCNP4a sample calculations from LEU-COMP-THERM-024 [1]

case no.	k_{eff}	σ	Uncertainty of the Benchmark Model k_{eff}
1	0.9967	0.0011	0.0054
2	1.0079	0.0013	0.0040

Table 1-4 Results of MCNP4a sample calculations from LEU-COMP-THERM-025 [1]

case no.	k_{eff}	σ	Uncertainty of the Benchmark Model k_{eff}
1	0.9946	0.0010	0.0041
2	1.0001	0.0011	0.0044
3	0.9989	0.0011	0.0047
4	1.0002	0.0010	0.0052

Table 1-5 Results of MCNP4a sample calculations from LEU-COMP-THERM-032 [1]

case no.	k_{eff}	σ	Uncertainty of the Benchmark Model k_{eff}
1	1.0005	0.0012	0.0045
2	0.9961	0.0011	0.0041
3	1.0044	0.0011	0.0042
4	1.0034	0.0010	0.0037
5	1.0018	0.0011	0.0032
6	1.0005	0.0012	0.0033
7	1.0047	0.0010	0.0045
8	1.0037	0.0010	0.0038
9	1.0044	0.0010	0.0037

The University of Florida with Sandia National Laboratories, Framatome, and Oak Ridge National Laboratory are currently setting up a critical experiment to obtain additional high enrichment criticality data at 6.93 wt% U^{235} to benchmark the Russian and English data. Current computer codes such as MCNP and CASMO/SIMULATE have been evaluated by the Nuclear Regulatory Commission and have been certified as being capable of calculating systems up to the five percent enrichment range. Further critical experiments in the five to ten weight percent range will allow the benchmarking of these codes and validate them for higher enrichments.

The International Criticality Safety Benchmark Evaluation Project (ICSBEP) was initiated in October of 1992 by the Department of Energy Defense Programs Systems Engineering Division. This project is managed through the Idaho National Engineering and Environmental Laboratory (INEEL) and involves nationally known criticality safety experts from Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Savannah River Technology Center, Oak Ridge National Laboratory and the Y-12 Plant, Hanford, Argonne National Laboratory, and the Rocky Flat Plant. An International Criticality Safety Data Exchange component was added to the project in 1994. Representatives from the United Kingdom, France, Japan, the Russian Federation, Hungary, Korea, Slovenia, Yugoslavia, Spain, and Israel are now participating on the project. The ICSBEP is an official activity of the OECD-NEA.

The work of the ICSBEP is documented as an International Handbook of Evaluated Criticality Safety Benchmark Experiments. Currently, the handbook spans over 22,000 pages and contains 307 evaluations representing 2462 critical configurations. The

handbook is intended for use by criticality safety analysts to perform necessary validations of their calculational techniques

Description of the Nuclear Fuel Cycle

Mining

The first three steps in the fuel cycle, mining, milling, and conversion, will not be affected in a criticality safety sense by an increase in enrichment. However, in order to develop an economic model, they will be included to quantify the entire fuel process Going to higher enrichments does change the feed requirements in relation to processing. Over half the world's production of uranium from mines is in Canada and Australia [2] In 1990 55% of world production came from underground mines, but this shrank dramatically to 33% in 1999 From 2000, this percentage increased due to new Canadian mines In 2001, production was as follows open pit 29%, underground 40%, in-situ leach (ISL) 16%, and by-product 15%

There are three methods used to mine uranium ore; open pit mining, underground mining, and solution mining (also called in-situ leaching) Back in 1986 about 97% of uranium ore came from surface mining. In open pit mining, holes are drilled to define the ore bed The topsoil is then removed and put aside so it can be used later to refill the pits Waste rock and other overburden are removed by large scrapers and hauled out by trucks Technicians use G-M counters to locate uranium ore Once the uranium ore bed is reached the ore is dug using small front-end loaders and loaded into ore hauling trucks to be transferred to the surface and stockpiled The ore is then taken to the mill by "suitable" over-the-road trucks

The ore in an underground mine may be below ground level by almost a mile. Side tunnels are cut into the ore deposits and the ore is removed, taken to the surface in mining carts, and hauled by trucks to the mill. Some disadvantages to this type of mining are as follows: part of the ore is left behind to support the roof of the mine, there is a potential for cave ins, and radon gas (^{222}Rn) from the uranium ore requires miners to wear masks in the ore producing sections of the mine, as well as radon detectors to measure the cumulative radiation dose. High ventilation flow, tens of miles per hour, is required to reduce the radon to manageable levels. An advantage of underground mining is that the surface area over the mine is left undisturbed. The Environmental Protection Agency (EPA) limit on radon concentration has made underground mining in the U.S. totally uneconomical.

Today approximately 85% of the US uranium production is from in-situ leaching (ISL). About 12 such ISL facilities exist in the United States. Of these, six are licensed by the NRC as shown in Table 1.6 and the rest are licensed by Texas. The largest uranium production facilities in the United States are Cameco's Smith Ranch and Highland facilities in Wyoming. The production life of an individual ISL well pattern is usually less than 3 years, typically 6-10 months. Most of the uranium is recovered during the first 6 months of the operation. The most successful operations have achieved a total overall recovery of about 80% of the ore. This process is also used to mine copper and gold.

In a typical ISL well five holes are drilled about 50 ft apart [3]. The middle and outside holes (injection wells) are used to inject the leaching solution (oxygenated and acidified groundwater) down to the ore where it dissolves the uranium. If there is

significant calcium in the orebody (such as limestone or gypsum), alkaline (carbonate) leaching must be used. Otherwise, acid (sulfate) leaching is used. The other two holes (retrieval wells) are used to suction up the dissolved uranium solution and carry it up to a resin ion exchange (IX) or liquid ion exchange (solvent extraction – (SX)) system (Figure 1-1). The choice is largely determined by the salinity of the groundwater. SX is better with high salinity. The uranium is then stripped from the ion exchange resin and precipitated chemically, usually with hydrogen peroxide. The uranium slurry is dewatered and dried to give hydrated uranium peroxide ($UO_4 \cdot 2H_2O$) product. Low temperature drying will yield U_3O_8.

Before the remaining process solution is reinjected, it is oxygenated and if necessary recharged with sulfuric acid to maintain a pH of about 2.5 to 2.8. Most of the solution is returned to the injection wells, but a very small flow (about 1%) is bled off to maintain a pressure gradient in the wellfield and this, with some solutions from surface processing, is treated as waste. This waste stream contains various dissolved minerals such as radium, arsenic and iron from the orebody and is reinjected into approved disposal wells in a depleted portion of the orebody. This bleed off process solution ensures that there is a steady flow into the wellfield from the surrounding aquifer and serves to restrict the flow of mining solutions away from the mining area.

Some advantages to in-situ leaching are the elimination of the crushing, grinding, and hauling of ore, elimination of large-scale excavations, a reduction of risks to miners from working underground, and a very small fraction (less than 5%) of the radioactivity of the ore reaches the surface. One disadvantage is the potential for contamination of the groundwater.

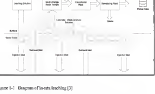

Figure 1-1 Diagram of in-situ leaching [3]

Milling

After the uranium has been mined it must be concentrated into U_3O_8, which is known as yellow cake. This process takes place in a uranium mill. The ore is crushed, ground into powder and then roasted to remove most of the organic material. This procedure is followed by either leaching, ion exchange or solvent extraction. The leaching agent not only extracts uranium from the ore, but also contains or produces several other constituents like molybdenum, vanadium, selenium, iron, lead, and arsenic. Then the uranium is precipitated out and washed. The resultant U_3O_8 is then centrifuged and dried, and finally packaged into 55-gallon steel drums. Most mills in the United States are being decommissioned; three are in standby mode, and one is in operation. A listing of uranium mills licensed by the NRC in the United States can be found in Table 1-6.

Table 1-6 In-situ leach and conventional uranium milling facilities licensed by the NRC [4]

Licensee	Site Name/Location
In-Situ Leach Facilities	
Cogema Mining, Inc.	Irigaray/ChR, Wyoming
Power Resources Inc.	Highlands Wyoming
Crow Butte Resources Inc	Crow Butte Nebraska
Rio Algom Mining Corp	Smith Ranch Wyoming
Hydro Resources Inc	Crown Point, New Mexico
Power Resources Inc.	Ruth and North Butte Wyoming
Conventional Uranium Milling Facilities	
International Uranium Corp.	White Mesa Utah
Umetco Minerals Corp	Gas Hills Wyoming
Western Nuclear Inc.	Split Rock Wyoming
Tennessee Valley Authority*	Edgemont, South Dakota
Pathfinder Mines Corp	Lucky Mc, Wyoming
American Nuclear Corp	ANC Wyoming
Pathfinder Mines Corp	Shirley Basin, Wyoming
Petrotomics Co	Shirley Basin Wyoming
Rio Algom Mining Corp.	Lisbon Utah
Exxon Mobil Corp	Highlands Wyoming
Bear Creek Uranium Co.	Bear Creek, Wyoming
Kennecott Uranium Co	Sweetwater, Wyoming
Plateau Resources Ltd	Shootaring, Utah
Homestake Mining Co	Homestake, New Mexico
Kennecott Energy Co	L Bar New Mexico
Rio Algom Mining LLC.	Ambrosia Lake New Mexico
UNC Mining & Milling	Churchrock New Mexico
Atlantic Richfield Co *	Bluewater, New Mexico

*Specific licenses terminated, disposal area under general license to the U S Department of Energy for long term care

Conversion to UF_6

The two processes used to convert the purified U_3O_8 are the dry hydrofluor process shown in Figure 1-2 and the wet solvent extraction process. In the dry hydrofluor process the U_3O_8 is first ground into a fine powder. Then the ground material enters a fluidized bed reactor where it is maintained at a temperature of 1000 to 1200 °F and reduced by hydrogen. The resulting product consists mainly of uranium dioxide (UO_2) which is a brown oxide. The chemical reaction follows.

$U_3O_8 + 2H_2 \rightarrow 2\,H_2O + 3UO_2$

Next the crude UO_2 is passed on to two successive hydrofluorination fluidized-bed reactors, where interaction occurs with anhydrous hydrogen fluoride (HF) at a temperature of 900 to 1000 °F. The chemical reaction that takes place is

$UO_2 + 4HF \rightarrow 2\,H_2O + UF_4.$

The resulting uranium tetrafluoride (UF_4), a green salt, is a nonvolatile solid with a high melting point (1700 to 1800 °F). It is treated at high temperatures with fluorine gas to form UF_6, according to the reaction

$UF_4 + F_2 \rightarrow UF_6$ (gas)

Since some volatile impurities do follow the UF_6, it must be further purified by fractional distillation resulting in a purified liquid. This liquid UF_6 is drained into 14-ton steel cylinders where, after cooling for 5 days, the UF_6 crystallizes [5]. The one conversion plant operating in the United States is the dry conversion plant owned by Honeywell International, Inc. and is located in Metropolis, Illinois [6]. Other countries that have conversion plants are Canada, France, United Kingdom, China, and the Russian Federation.

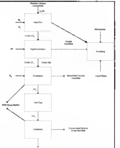

Figure 1-2. Flow chart of the dry hydrofluor process to convert U_3O_8 to UF_6 [3, 6]

The wet solvent extraction process (not used in the US) also uses reduction, hydrofluorination, and fluorination steps but they are preceded by solvent extraction to remove impurities. Thus, fractional distillation is unnecessary since the UF_6 produced by this process is pure. This process is shown in Figure 1-3.

Figure 1-3 Flow chart of the wet solvent extraction-fluorination process to convert U_3O_8 to UF_6 [3]

UF_6 is a solid white material at room temperature within the transport container. During transport the pressure inside the containers is kept below the outside atmosphere pressure. UF_6 is not flammable, not explosive and inert in dry air. It does, however, react with water. The humidity of the air is sufficient to cause it to undergo a rapid conversion into water soluble uranyl fluoride (UO_2F_2) and hydrogen fluoride (HF). In the presence of excess water, hydrogen fluoride forms hydrofluoric acid, which is a deadly material and causes serious burns on contact. But even at very low concentrations, long before a possible health threat, HF is clearly visible as a grey white fog.

Enriching

The isotope found in uranium which most readily splits (fissions) in a commercial nuclear reactor is U^{235}, but only 0.711-wt% of naturally occurring uranium is U^{235}. Commercial fuel is currently licensed to 5-wt% U^{235} for use in commercial nuclear reactors. Natural occurring uranium contains three isotopes, uranium 234 (U^{234}), uranium 235 (U^{235}), and uranium 238 (U^{238}). Natural uranium contains 0.0054-wt% U^{234} which occurs as part of the decay chain of U^{238}. The greater part of the radioactivity of uranium results from U^{234}. All three isotopes have identical chemical properties so the major way they can be separated is by their mass. U^{238} is heavier than U^{234} and U^{235}. Although the U^{234} is not desired in the enriched fuel, increased concentrations of it are a by-product of the enriching process.

The Paducah Gaseous Diffusion Plant in Paducah, Kentucky, is currently the only operating uranium enrichment facility in the United States [7, 8]. Owned by the U.S. Department of Energy, it is leased and operated by the United States Enrichment

Corporation, a wholly owned subsidiary of USEC, Inc The plant was opened in 1952 as part of a U S government program to produce highly enriched uranium to fuel military reactors and produce nuclear weapons. Enrichment at Paducah originally was limited to low levels, and the plant served as a "feed facility" (producing 2 0 wt% U^{235}) for other enriching plants in Oak Ridge, Tennessee, and Portsmouth, Ohio, where the enriched uranium was processed to higher levels That mission changed in the 1960s, when Paducah, along with its sister plant at Portsmouth, began to enrich uranium for use in commercial nuclear reactors to generate electricity The Portsmouth plant began production in 1954 and operated almost exclusively for national defense purposes until 1964 In May 2001, enrichment operations at Portsmouth were discontinued and consolidated at the Paducah plant which was upgraded to handle 5 wt% U^{235} The Paducah plant currently has a design capacity of approximately 11 million separative work units (SWUs) per year The USEC is also currently planning construction of a centrifuge enrichment plant with a partner and has exclusive rights to a laser enrichment technology called SILEX that is being developed by Silex Systems Ltd. of Australia. This selection of the Paducah enrichment facility for continued operation and production of higher wt% fuel represents a major challenge in the effort to license higher enriched reload fuel.

For the gaseous diffusion process, the transport container and the contained UF_6 are heated in a chamber (autoclave) for feeding into the plant. UF_6 is a solid at room temperature but becomes a gas when heated above 135 degrees Fahrenheit First the pressure of the UF_6-vapor increases as it evaporates from the solid UF_6, at 147 °F UF_6 becomes a liquid and the pressure increases to 1 5 bar Before the UF_6 is piped into the

cascades the pressure is lowered to 50 mbar (1/20 of normal atmospheric pressure). At this pressure, UF_6 remains gaseous within the pipes even at environmental room temperature. The gas is forced through a series of porous membranes with microscopic openings with a pressure differential. The process separates the lighter U^{234} and U^{235} isotopes from the heavier U^{238}. Because the U^{234} and U^{235} are lighter and energy is conserved, they strike the barriers more often and thereby have a greater chance of moving through the barrier. As the gas diffuses, the isotopes are separated increasing the U^{234} and U^{235} concentrations and decreasing the concentration of U^{238}. The enriched and depleted UF_6 leaving the plant is solidified again in transport containers.

In May 1999 USEC decided to abandon the Advanced Vapor Laser Isotope Separation (AVLIS) enrichment process as its future technology. The AVLIS process used lasers passing through high-temperature uranium metal vapor to selectively excite the U^{235} isotope, ionize it, and separate the U^{235} in order to produce enriched uranium. There were reports that although the physics of atomic laser separation was quite effective, the engineering obstacles associated with handling vaporous uranium metal may have been too difficult or costly to overcome. The decision to terminate AVLIS leaves USEC with essentially two long-term technology options, the Silex process, under early-stage development in Australia, or centrifuge separation, long used by Russia and the European consortium Urenco. The Silex process also employs lasers to separate isotopes, but the feed is in molecular (UF_6) form, which is relatively easy to handle at low temperatures and is the industry standard for enrichment. The effectiveness of this process at commercial scale is unknown at present.

On February 12, 2003, USEC submitted a license application for a gas centrifuge uranium enrichment test facility or "lead cascade" [9] The lead cascade will be based on U.S. Department of Energy's (DOE) advanced gas centrifuge technology The USEC objective is to replicate the existing technology and reduce costs using advances in carbon fiber and other material and manufacturing technologies The USEC program would be performed in the following three phases: (1) A demonstration program under DOE auspices and regulatory control, (2) the lead cascade phase, and (3) the commercial deployment phase.

The demonstration phase is intended to obtain detailed test data for the gas centrifuge machines. The lead cascade phase is intended to provide reliability information on the machines auxiliary systems as it would be used in commercial operations. The lead cascade, consisting of 240 centrifuges, will recycle the enriched and depleted uranium it produces. The only uranium withdrawals from the cascade will be in the form of samples. In the commercial deployment phase, the commercial plant would have a capacity of 3.5 million SWU per year, with up to 10% enrichment. In a letter dated January 27 2004, to the NRC, USEC Inc stated its intent to submit a license application to the NRC in August 2004, for the American Centrifuge Plant (ACP), to be located in Piketon, OH

Louisiana Energy Services (LES) submitted a license application on December 12, 2003, to construct and operate a gas centrifuge uranium enrichment facility [10] The LES partnership is made up of limited and general partners currently consisting of Urenco Exelon, Duke Power, Entergy, and Westinghouse. The partnership intends to use Urenco's sixth generation gas centrifuge technology that is currently being used in

Europe Currently, Urenco has a capacity of about 15 percent of the world's enrichment market. Full capacity of 3 million SWU/yr is projected to be in 2010 or 2011 depending on market demand On September 2, 2003, LES announced its final site selection to be Eunice, New Mexico

The gas centrifuge method was developed in Germany during the second world war, but the actual application only started in the 50s and 60s The advantage over the gas diffusion method is that this technique separates isotopes more efficiently using less energy (less units have to be connected to a cascade to reach the same enrichment) However, a very high technology is necessary to manufacture the machines (precision and reliable bearings, corrosion resistant rotating parts of sufficient endurance) The gas centrifuge uranium enrichment process uses a large number of rotating cylinders in series to enrich uranium in its U^{235} isotope These series of centrifuge machines, called trains, are interconnected to form cascades. The gas centrifuge is essentially a bowl, in which there is a rotor spinning round at a very high speed. The gas (UF_6) directed to the centrifuge is forced to spin by the rotor Due to the centrifugal force the heavier molecules (those which contain U^{238}) will accumulate near the wall of the bowl, while the lighter molecules containing U^{234} and U^{235} will stay closer to the center of the centrifuge A diffusion plant typically uses 2,400 kilowatt hours per separative work unit (kWh/SWU) while a modern centrifuge plant requires 40 to 100 kWh/SWU

One other source of enriched uranium is the downblending of high-enriched weapons grade uranium BWX Technologies (BWXT) and the U S Enrichment Corporation have a contract for BWXT to downblend 50 metric tons of high-enriched uranium deemed excess to the nuclear weapons program [11] The downblending will be

performed over a six-year period and will produce low-enriched uranium suitable for use in light water reactors. The Nuclear Regulatory Commission (NRC) staff received a license request on August 7, 2001, and a revision to that submittal dated December 18, 2001. The request was to amend their license to authorize the installation and use of the Metal Dissolution Facility (MDF) for the dissolution of high enriched uranium (HEU) metal to support BWXT's downblending operations. The BWXT facility in Lynchburg, VA, is authorized to possess nuclear materials for the fabrication and assembly of nuclear fuel components. The facility supports the U.S. naval reactor program, fabricates research and university reactor components, and manufactures compact reactor fuel elements. The facility also performs recovery of scrap uranium. Research and development activities related to the fabrication of nuclear fuel components are also conducted. The MDF will be used to receive, store, and dissolve HEU metal ranging from 20 to 97 percent U^{235}. The MDF will support other processing areas and will be located within the Bay 15A Material Access Area (MAA). The building is already in place, so there will be no new construction on the BWXT site. The purpose of the MDF is to produce a homogeneous uranyl nitrate solution with a uranium concentration of approximately 400 grams/liter (g/l). The first step in the MDF is the weighing out of an appropriate amount of HEU in a charging basket in a ventilated glove box. The charging basket is then transferred via a lift to a dissolver digester. Measured quantities of nitric acid and deionized water are added in the dissolver to dissolve the HEU. The resulting mixture is then heated to approximately 180 degrees Fahrenheit and circulated until a homogeneous uranyl nitrate solution is made. This homogeneous uranyl nitrate solution is then pumped through filters into a process monitoring column where the solution is circulated, weighed, and

sampled for U^{235} concentration. The solution is then transferred via a manually activated pump to one of five storage columns where it is retained until required for blending with depleted or low enriched uranium

A second source of enriched uranium from the downblending of high-enriched weapons grade uranium will be the Nuclear Fuels Services, Inc. (NFS) facility located in Erwin, Tn [12] NFS is currently manufacturing high enriched nuclear reactor fuel at this facility NFS is constructing a new complex at the Erwin site to manufacture low-enriched nuclear reactor fuel They also have requested amendments to their license to authorize activities associated with the preparation of blended low-enriched uranium (BLEU) from surplus highly-enriched uranium from the U S Department of Energy These activities would be performed under a contract with Tennessee Valley Authority (TVA) to provide low-enriched fuel to be used in TVA's Brown's Ferry Nuclear Plant in Alabama. NFS has requested authorization to perform dissolution of highly-enriched uranium/aluminum alloy and uranium metal and downblending of the resulting solution into low-enriched uranyl nitrate solution, authorization to store low-enriched uranyl nitrate solution in a new tank storage facility on the NFS plant site, and authorization to perform conversion of the low-enriched uranyl nitrate solution into uranium dioxide powder

Fuel Processing and Fabrication

Currently there are three U S. fuel fabrication facilities which are capable of converting the UF_6 gas to solid UO_2 [13] Framatome ANP Richland Division, Inc (formerly Siemens Power Corporation) has its Engineering and Manufacturing Facility located in Richland, Washington The Engineering and Manufacturing Facility holds a

license from the NRC (SNM-1227, Docket No 70-1257) authorizing the following activities manufacture of nuclear fuel, including all operational steps from UF_6 to UO_2 conversion through packaging finished fuel elements with uranium compounds up to 5 wt% U^{235}, all operational steps of dry UF_6 to UO_2 conversion and UO_2 powder preparation for uranium compounds up to 5 wt% U^{235}, storage of a planar array of closed containers of uranium oxide (up to 5 wt% U^{235}) pellets that are externally free of significant contamination, unloading from shipping containers and storage of containers of uranium compounds up to 5 wt% U^{235} (product, scrap and waste materials), outside storage of up to 5 wt% U^{235} enriched UF_6 cylinders (full and empty), outside storage of fuel (UO_2 up to 5 wt% U^{235}) packed for shipment, and UF_6 (solid and in waste solution up to 5 wt% U^{235}) cylinder recertification activities. Uranium is processed using dry conversion as shown in Figure 1-4 The dry process changes UF_6 into a ceramic grade uranium dioxide powder in a single stage by mixing it with steam and hydrogen in a kiln The UF_6 is reduced to UF_4 by adding hydrogen in great excess, then water mixes with the UF_4 to produce UO_2 and HF The UO_2 powder goes through a calciner and then into one of two storage hoppers Two different enrichments from the storage hoppers are mixed into the blender to make the required enrichment The powder then flows through a hammermill, roll compactor, quadro mill and then into a 45-gallon storage drum The storage drum is then transferred to the pelletizing area. The powder is emptied into a rotary press where it is pressed into cylindrical pellets and put into boats The boats go through a walking beam sintering furnace The pellets are then ground to a finished size using a grinding wheel and placed on trays. The fuel pellets are shipped to Framatome's Lynchburg facility where they are loaded into zircaloy tubes in which one end plug has

been welded The tubes are placed into a welding machine which is first evacuated then backfilled with helium gas The rods are welded shut and are then placed in a vacuum chamber and tested for leaks The rods are then assembled into an assembly with grid plates, spacer grids, and top nozzles. The Engineering and Manufacturing Facility has a current operating capacity of approximately 700 metric tons HM/yr or 1,035 metric tons UF_6/yr and is limited to possession of no more than 25,000 kg of U^{235} in uranium compounds that have been enriched to no more than 5 wt%.

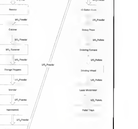

Figure 1-4 Framatome ANP's Dry Conversion and Palletizing Process [13]

Westinghouse Electric Company LLC Columbia Fuel Fabrication Facility is located in Columbia, South Carolina The Columbia Fuel Fabrication Facility (CFFF) is primarily engaged in the manufacture of fuel assemblies for commercial nuclear reactors Two processes are installed at the CFFF for converting UF_6 to UO_2 powder the ammonium diuranate (ADU) process and the integrated dry route process (IDR) However, the integrated dry route process has been mothballed The CFFF has a current operating capacity of 1,700 metric tons UF_6/yr or 1,150 metric tons heavy metal per annum and is limited to no more then 75,000 kg of U^{235} in any chemical and/or physical form of uranium (except metal) that has been enriched to no more than 5 wt% The CFFF holds a license from the U S Nuclear Regulatory Commission (NRC) (SNM-1107, Docket No. 70-1151) authorizing among others, the following activities (1) Low enriched (less than or equal to 5 0% by weight) U^{235} is received in the form of UF_6 This portion of the plant receives the UF_6 containers which are stored outside of the plant until used (2) UF_6 is converted to UO_2 powder In this process the UF_6 containers are placed into a vaporizer where the UF_6 is sublimed into the process line where it is dissolved in H_2O to form a UO_2F_2 solution which is mixed with NH_4OH to form an ammonium diuranate (ADU) slurry The slurry is then centrifuged to separate the ADU and the wet ADU is then dried and calcined (dried at high temperature) to form U_3O_8 Then it is further reduced with hydrogen to form UO_2 powder which is then milled and blended in preparation for the pelletizing operation. (3) The UO_2 powder is then pressed and sintered into pellets (4) The pellets are loaded into fuel rods and sealed (5) The rods are then loaded into fuel assemblies. Figure 1-5 presents a flow chart of the ADU process used by Westinghouse and Global Nuclear Fuel for UF_6 conversion to UO_2

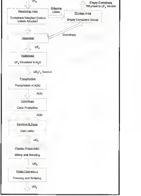

Figure 1-5 ADU process flowchart [13]

Global Nuclear Fuel (Formerly General Electric) – Americas (GNF-A), LLC is located in Wilmington, North Carolina. The GNF-A holds a license from the NRC (SNM-1097, Docket No 70-1113) authorizing it to conduct the following activities among others: conversion of UF_6 to uranium oxides by the ADU process and the dry conversion process, operation of process technology for the purpose of converting UF_6 to UO_2 and other intermediate compounds by chemical and dry processes, storage of unirradiated fuel assemblies and uranium compounds and mixtures in areas arranged specifically for maintenance of criticality and radiological safety, and design, fabrication, and testing of uranium prototype processing equipment GNF-A has a current operating capacity of 1,200 metric tons HM/yr (1,775 metric tons UF_6/yr) and is limited to no more then 50,000 kg of U^{235} contained in uranium (in any chemical and/or physical form) enriched to no more than 5 wt% U^{235} The location of GNF-A as well as the other major fuel cycle facilities are shown in Figure 1-6

When the fuel fabrication facility is finished assembling the fuel assemblies, they are shipped to the reactor Typically, two fuel assemblies are stored in a transport cask and are shipped by truck, with each truck carrying 6 casks.

Interim Storage and Final Disposal

When the utility receives the fresh fuel assemblies they are inspected and moved into the spent fuel pool for temporary storage until they can be placed into the reactor Anywhere from one-fourth to one-half of the total fuel load is removed from the reactor every 12 to 24 months and replaced with fresh fuel The spent fuel is placed into a spent fuel pool for temporary storage. The spent fuel pool must always have the capacity to offload the entire reactor core. The pool is a concrete reinforced structure designed to

Licensee	Location
Uranium Fuel Fabrication Facilities	
Global Nuclear Fuel Americas LLC	Wilmington, North Carolina
Westinghouse Electric Company, LLC	Columbia, South Carolina
Nuclear Fuel Services, Inc.	Erwin, Tennessee
Framatome ANP Inc	Lynchburg Virginia
BWX Technologies, Inc	Lynchburg, Virginia
Framatome ANP Inc	Richland Washington
Uranium Hexafluoride Production (Conversion) Facility	
Honeywell International, Inc.	Metropolis, Illinois
Gaseous Diffusion Enrichment Facilities	
U S Enrichment Corporation	Paducah Kentucky
U S Enrichment Corporation	Piketon Ohio

Figure 1-6 Locations of major fuel cycle facilities [4]

withstand seismic events and with a stainless steel liner to prevent leakage Approximately 23 feet of water is contained in the pool above the level of fuel to provide radiation shielding A typical cooling system has two pumps and two heat exchangers. Both the suction and discharge of that system are arranged either high in the pool or with some anti-siphon features, so that the water in the pool cannot be drained out down to the level where the fuel is.

An important safety function of the spent fuel pool is reactivity control. This is controlled by the geometry itself, separation of the fuel assemblies by analysis of the reactivity of the individual fuel assemblies and by fixed neutron absorbing material which in some designs is attached to the fuel rack itself Soluble boron is not used to maintain subcriticality of the fuel in the rack itself but it provides additional margin for conditions such as inadvertently loading the fuel in an unexpected arrangement or condition, for example, if a fuel assembly were to be dropped and be laying across the top of the racks, that would be a more reactive configuration In the past it was necessary to show that the fuel remained 5 percent subcritical with no credit for boron. Today, boron is credited so that the pool only needs to remain subcritical It must be shown that if there was a loss of boron in the pool, the fuel would remain subcritical Such an event could be caused by putting fire water or service water or some other water into the spent fuel pool

A second option for spent fuel storage is dry cask storage This storage can be used to increase spent fuel storage capacity Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year and usually five to ten years to be surrounded by inert gas inside a container called a cask. The casks are typically steel cylinders that are either welded or bolted closed The steel cylinder

provides a leak-tight containment of the spent fuel Each cylinder is surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and members of the public Some of the cask designs can be used for both storage and transportation.

There are various dry storage cask system designs. With some designs the steel cylinders containing the fuel are placed vertically in a concrete vault, other designs orient the cylinders horizontally The concrete vaults provide the radiation shielding Other cask designs orient the steel cylinder vertically on a concrete pad at a dry cask storage site and use both metal and concrete outer cylinders for radiation shielding. The first dry storage installation was licensed by the NRC in 1986 at the Surry Nuclear Power Plant in Virginia Spent fuel is currently stored in dry cask systems at a growing number of power plant sites as shown in Figure 1-7, and at an interim facility located at the Idaho National Environmental and Engineering Laboratory near Idaho Falls, Idaho A listing of NRC approved designs for dry spent fuel storage is shown in Table 1-7

The current proposed US strategy for final disposal of spent nuclear fuel is to store the spent fuel assemblies in Yucca Mountain A 1 mil/kwhr, fee is imposed on the fuel while it is being burned in the reactor to pay for the eventual long term storage The U S Department of Energy's (DOE s) high level radioactive waste repository is not expected to begin receiving spent fuel until approximately 2010, at the earliest. Reprocessing of spent fuel in the United States is not a viable alternative at this time since there are no operating or planned commercial reprocessing facilities in the United States Therefore spent fuel would have to be shipped to an overseas facility for reprocessing However this approach has never been used and it would require approval

by the Department of State as well as other entities. Additionally, the cost of spent fuel reprocessing is not offset by the salvage value of the residual plutonium and uranium. Thus, reprocessing represents an added cost over disposal.

Table 1-7. Dry spent fuel storage designs approved by the NRC for general use [14]

Vendor	Storage Design Model	Certificate of Compliance Issue Date	Docket
General Nuclear Systems, Incorporated	CASTOR V/21	08/17/1990	72.1000
Westinghouse Electric	MC-10	08/17/1990	72.1001
NAC International, Inc.	NAC S/T	08/17/1990	72.1002
NAC International, Inc.	NAC-C28 S/T	08/17/1990	72.1003
Transnuclear, Incorporated	TN-24	11/04/1993	72.1005
BNFL Fuel Solutions Corp	VSC-24	05/03/1993	72.1007
Transnuclear West, Inc	Standardized NUHOMS-24P NUHOMS-52B	01/18/1995	72.1004
Holtec International	HI-STAR 100	10/04/1999	72.1008
Holtec International	HI-STORM 100	05/31/2000	72.1014
Transnuclear Inc.	TN-32	04/19/2000	72.1021
NAC International	NAC-UMS	11/20/2000	72.1015
NAC International	NAC-MPC	04/10/2000	72.1025
BNFL Fuel Solutions	FuelSolutions	02/15/2001	72.1026
Transnuclear, Inc	TN-68	05/30/2000	72.1027

Figure 1-7 Locations of independent spent fuel storage installations [15]

CHAPTER 2
DETERMINATION OF CRITICALITY LIMITS

Overview of Modeling

In this report, the entire fuel cycle was studied and evaluated for effects of going to higher enrichments for criticality safety. This criticality constraint is considered the limiting constraint for the utilization of enrichments greater then 5 wt% U^{235}. Traditionally in criticality safety analysis, material configurations have been considered safe from a criticality standpoint if the predicted value of k_{eff} is less than 0.95. Two standard criticality codes MCNP4c2 and MCNP5 mpi were used [16]. MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Pointwise or multigroup cross-section data are used. For neutrons, all reactions given in a particular cross- section evaluation (such as ENDF/B-VI) are accounted for. Thermal neutrons are described by both the free gas and S(alpha,beta) models.

To carry out this study criticality models of fuel processing equipment, fuel assemblies, shipping containers, and fuel storage were developed using MCNP. Enrichments of 5-wt% to 20-wt% U^{235} in increments of 1 wt% were examined. The results from these analyses were used to assign economic penalties to each aspect of the

nuclear fuel cycle for increasing the allowable U^{235} wt% at each increment. The economic penalties were assigned for restrictions or costs incurred at each point in the fuel cycle in order to maintain criticality safety.

UF_6 30B Shipping Container

The initial fuel processing operation is the enriching of the uranium either in a gaseous diffusion plant or a gaseous centrifuge plant. The uranium is processed as UF_6 and is stored and shipped to the commercial nuclear fuel processing facilities as UF_6. Commercial fuel fabrication facilities typically receive UF_6 in 30B cylinders. A 30B cylinder has a nominal diameter of 30 inches and a nominal length of 81.5 inches [17]. A steel skirt extends 5 inches from the cylinder head to protect the cylinder and the valve. Only 76 inches of the 81.5 inch nominal length of the cylinder contain UF_6. For the purposes of this analysis, the cylinder was modeled as a right circular cylinder. The maximum permissible cylinder fill weight of UF_6 is 2,277 kg. More material can be physically placed in the cylinder during filling, but adding material beyond this weight limit increases the possibility of hydraulically rupturing the cylinder on subsequent reheating. During the withdrawal of UF_6, operating procedures require that condenser pressures and temperatures be near those of saturated UF_6 to assure that impurities are not present. The gaseous diffusion cascade consistently produces high-purity UF_6 (i.e. greater than 99.5 weight percent UF_6). For nuclear criticality safety purposes, all impurities are conservatively assumed to be HF. Assuming that UF_6 is 99.5 pure weight percent and that the other 0.5 weight percent is HF, an H/U atomic ratio of 0.088 is obtained.

A worst case scenario was modeled in which solid UF_6, moderated by HF (at an H/U ratio of 0.088) was filled to the top of the 30B cylinder with a 2 foot water reflector surrounding the cylinder. Further models were developed of an infinite array of 30B cylinders, stacked one high with interstitial water and a concrete reflector to simulate conditions such as rain or a sprinkler system. Various moderators consisting of air, water, or water vapor of varying densities were modeled. Models were also developed of an infinite horizontal array, stacked two high in a triangular pitch, placed on a 1 ft concrete slab and are shown in Figure 2-1.

Figure 2-2 shows the results of the infinite triangular pitch array of 30B containers. The most limiting moderators were the 0.2 and 0.3 g/cc vapor cases. At lower enrichments (below 10 wt% U^{235}) the 0.2 g/cc case is more limiting. At the higher enrichments the 0.3 g/cc case becomes more limiting. These cases show that the 30B container would be limited to carrying enriched UF_6 of 10-wt% or less of U^{235} which would be enough for the commercial gas centrifuge uranium enrichment the United States Enrichment Corporation (USEC) plans to develop and build. The results of all MCNPc2 calculations of models of the 30B container are presented in Tables B-1 through B-19 of Appendix B.

Wet Processing of UF_6 to UO_2

Typical dimensions for plant processing equipment, which will ensure nuclear criticality safety in the wet processing of up to 20 w/o U^{235} uranium regardless of the values of any other parameters in the system, were modeled. A pipe was modeled conservatively as a cylinder of infinite length. Further conservatism was introduced by assuming that the pipe was surrounded by an annular thickness of 1 foot of water, providing moderation

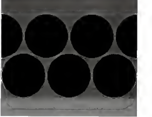

Figure 2-1 Side view of triangular pitch array of UF_6 filled 30B containers

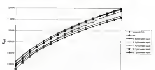

Figure 2-2 Results of MCNP4c2 calculations of UF_6 in 30B cylinders in a triangular pitch, completely filled, lying on a concrete slab

and reflection of neutrons that leak out the side of the pipe The material assumed was a homogeneous slurry of $UO_2 + H_2O$ In a system which does not process elemental uranium, a slurry of uranium dioxide provides maximum reactivity [18] The values of k_{eff} for 6, 8, and 10 inch (where applicable) diameter schedule 40ST SS piping of infinite length surrounded by one foot of water were calculated

Tables B-20 through B 31 of Appendix B present the cases analyzed using MCNP4c2 The results show that without moderation control, wet processing of UF_6 is viable using standard 8" diameter piping for enrichments from 5 to 10-wt% U^{235} range Wet processing of enrichments of greater then 10-wt% range should limit all piping to standard 6" diameter piping.

Dry Conversion Processing of UF_6 to UO_2

In the dry process, UF_6 is changed into a ceramic grade uranium dioxide powder in a single stage by mixing it with steam and hydrogen in a kiln. An original KENO model of the kiln used at a vendor site was obtained (Calvin Manning, Framatome ANP, personal communication, March 13, 2003). Using this as a base model, MCNP models were developed The MCNP models consisted of an upper section of 2.222 g/cc uranium-water slurry with the dimensions of 19 05 cm by 99 06 cm by 121 92 cm The lower section was 11 43 cm by 86 36 cm by 198 12 cm and filled with a denser 2 8175 g/cc uranium-water slurry Both sections were surrounded by 0 635 cm thick inconel, and placed into a "box" of moderator of the dimensions 49 8 cm by 135 89 cm by 331 47 cm Various moderators consisting of air, water, or water vapor of varying densities were modeled in order to determine the optimum moderation Insulation 13-cm thick around the moderator was modeled as a 0.3309 g/cc mixture of 51% SiO_2 and 49%

Al_2O_3. The results shown in Figure 2-3 and Tables B-32 through B-35 of Appendix B indicate that the current kiln would be limited to approximately 8-wt% U^{235}. An increase of enrichment beyond this point would require replacement of the current kiln with one that possessed smaller geometric dimensions in order to ensure criticality safety.

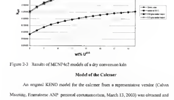

Figure 2-3 Results of MCNP4c2 models of a dry conversion kiln

Model of the Calciner

An original KENO model for the calciner from a representative vendor (Calvin Manning, Framatome ANP personal communication, March 13, 2003) was obtained and an MCNP model was developed using 5-wt% U^{235} fuel and an accident situation with water moderator. The calciner was modeled as a cylinder 618 cm in length with a radius of 12.7 cm containing a 2.816 g/cc uranium-water slurry. The calciner wall was composed of 7.87 g/cc carbon steel and was 1.27 cm thick. The cylinder was surround by a 48.26 cm by 48.26 cm by 618 cm shroud, the upper half of which was filled with air and the lower half modeled as a 2.222 g/cc uranium-water slurry. Two 7.62 cm thick heaters were modeled on the front and back of the calciner and were composed of 0.1281

g/cc mixture of 51% SiO_2 and 49% Al_2O_3. This same mixture at a density of 0.0961 g/cc was used in the model as the 15.875 cm thick insulation around the calciner. An additional 30 cm of moderator was added to simulate accident conditions. No further models were developed as this case showed that the current calciner was at the 0.95 k_{eff} limit under accident conditions. This limitation was confirmed with discussions with the calciner manufacturer (D. Dahlstrom ALSTOM, personal communication, May 21, 2004) and it is concluded that the calciner would have to replaced with another model with a smaller diameter (8 or 9 inches as opposed to the current diameter of 10 inches) to ensure criticality safety.

45-Gallon UO_2 Powder Storage Drums

Once the UO_2 is converted to powder it is typically stored in 45-gallon containers until it is used to form pellets. These drums are modeled as a cylinder with an inner radius of 28.575 cm, a height of 66.038 cm and with 0.1651 cm thick stainless steel walls, bottom, and lid (Calvin Manning, Framatome ANP, personal communication, March 13, 2003). The powder in the barrels was assumed to be composed of 4.0 g/cc UO_2 and 0.2105 g/cc water. Models were developed of a single barrel completely filled with powder and reflected on all sides by water at 20 °C. Additional models were developed of an infinite array of these barrels of one vendor design containing two rings of 8 H_3BO_3 poison rods with one poison rod in the center and is shown in Figure 2-4. The poison rods were 2.3114 cm in radius with 0.0635 cm thick air gap inside a 0.1651 cm thick steel clad. Various moderator ratios consisting of air, water, or water vapor of varying densities were modeled in order to define the optimum moderation.

The results of the infinite array of UO_2 filled 45-gallon containers are shown in Figure 2-5. The most limiting moderator was the 0.3 g/cc vapor case. These cases show that the current 45-gallon container would be limited to enriched UF_6 of 11-wt% or less of U^{235} which is sufficient for the USEC commercial gas centrifuge uranium enrichment facility. The results of the MCNPe2 calculations of models of the 45 gallon containers are presented in Tables B-36 through B-42 of Appendix B.

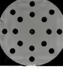

Figure 2-4 Top view of one element of an infinite array of UO_2 filled 45-gallon containers showing center and two rings of poison rods

Molybdenum Pellet Boats and Storage Shelves

Once the UO_2 powder is formed into pellets they are placed into molybdenum boats and go through a sintering furnace. Afterwards the boats are typically placed on stainless steel shelves. An original KENO model of the molybdenum boats used by a representative vendor was obtained (Calvin Manning, Framatome ANP, personal communication May 27, 2003). Using this as a base model MCNP models were developed. The first models developed were single boats filled with UO_2 pellets and water at 20 °C. Two sets of criticality models were developed to bound the potential U/H

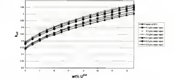

Figure 2-5 Results of MCNP4c2 models of infinite array of UO_2 filled 45-gallon containers

ratio. One set assumed 9.3% water and 90.7% UO_2 by volume, the maximum amount of UO_2 that would be able to be put into a boat assuming cylindrical pellets. The 2[nd] set of models assumed a 2 to 1 ratio of water to UO_2. Results show that the 2[nd] set of models was more limiting for the single boat case. Next, a model was developed using a 2 to 1 ratio of water to UO_2 of an infinite array of boats stacked one high on a ¼ inch stainless steel shelf, with 1 foot of water or water vapor moderator on all sides, with reflective boundaries. The results shown in Figure 2-6 and in Tables B-43 through B-47 indicate that the boats would be limited to approximately 12-wt% U^{235}. This is greater than the 10-wt% limit of the USEC commercial gas centrifuge uranium enrichment in development.

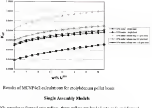

Figure 2-6 Results of MCNP4c2 calculations for molybdenum pellet boats

Single Assembly Models

After the UO_2 powder is formed into pellets, these pellets are loaded into rods and formed into assemblies. MCNP decks of single 15x15 and 17x17 fuel assemblies were developed. For both assembly types the maximum theoretical UO_2 density of 10.96 g/cc was used. For the 15x15 assembly, the fuel pin outer diameter was assumed to be 0.3622 inches, with an inner clad diameter of 0.37 inches, outer clad diameter of 0.414 inches, and a pin pitch of 0.568 inches [19]. The 17x17 assembly was modeled with a fuel pin diameter of 0.3252 inches, inner clad diameter of 0.331 inches, an outer clad diameter of 0.372 inches, and a pin pitch of 0.502 inches. Both models used an active fuel length of 144 inches and enveloped the single assemblies inside a right circular cylinder of 20 C water with a radius of 19.91 inches and a height of 199.75 inches. In single assembly runs it was shown that the 15x15 assembly is slightly more reactive then the 17x17 assembly so all later models used the 15x15 assembly. Further models were developed with addition of stainless steel rods or BPRAs placed in the guide tubes. Single assembly

runs show that assemblies must have some sort of moderation control above 5-wt% U^{235}. This would require either the addition of steel rods, BPRAs, or some other absorber when the assembly is constructed, during transportation, and placement into the spent fuel pool. As shown in Figure 2-7, the addition of steel rods would allow enrichments up to approximately 6.5-wt% U^{235} and BPRAs would increase that limit to approximately 12-wt% U^{235}. The results of all MCNP5 mpi calculations of models of single assembly models are presented in Tables B-48 through B-50 of Appendix B.

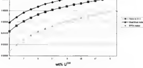

Figure 2-7 Results of MCNP4c2 models of a single 15x15 assembly in water at 20 °C

Fresh Fuel Shipping Casks

The assemblies are then shipped from a vendor to the nuclear plants in shipping casks. Using the licensed specifications of the Model B package [19, Larry Hassler, Framatome ANP, personal communication, January 27, 2004] infinite arrays of shipping casks were modeled. These casks were modeled as a cylinder with an outer radius of 50.574 cm, a height of 507.367 cm and with 0.3175 cm thick stainless steel walls, bottom, and lid. Two assemblies were placed in the center of the barrel on a steel plate,

with two borated steel plates separating them. The distance between the two borated steel plates is 5.87 cm. The casks were reflected on four sides with 60.96 cm of water above and below the casks. This model is shown in Figure 2-8. In single assembly runs it was shown that the 15x15 assembly is slightly more reactive then the 17x17 assembly so all cask models used the 15x15 assembly. Various moderator ratios consisting of air water, or water vapor of varying densities were modeled in order to define the optimum moderation. The results of the infinite array of shipping containers are shown in Figure 2-9. The most limiting moderator was the water at 20 °C case. These cases show that the selected cask would be limited to enriched UO_2 of 6-wt% or less of U^{235}. In addition, models were developed with stainless steel rods or BPRAs placed in the guide tubes. The results of these runs, shown in Figure 2-10, indicate that the addition of steel rods would allow shipping of fuel enriched up to 8-wt% U^{235} and BPRAs would increase that limit up to 15-wt% U^{235}. The steel plate supporting the two assemblies and the two borated plates separating them allow for a less critical situation then one assembly by itself with no poison material. The results of all MCNP5 mpi calculations of models of the Model B assembly shipping container are presented in Tables B-51 through B-59 of Appendix B.

Spent Fuel Pool

A typical spent fuel pool limiting configuration for fresh fuel bundles [20] was modeled as shown in Figure 2-11. The fresh fuel locations, shown in grey, are modeled as the 15x15 assemblies in the previous report. Each assembly location is surrounded by 0.2521 cm of water in a 0.1905 cm thick steel sheath. Each sheath is separated by 3.429 cm of water. The entire spent fuel pool rack was surrounded by 60.96 cm of water. Two criteria are typically used in a criticality safety analysis for the spent fuel pool. The first

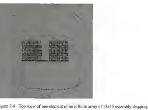

Figure 2-8 Top view of one element of an infinite array of 15x15 assembly shipping containers

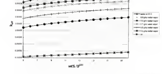

Figure 2-9 Results of MCNP4c2 models of infinite array of 15x15 assembly shipping containers in various water densities and air

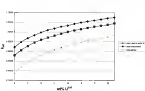

Figure 2-10 Results of MCNP4c2 models of infinite array of 15x15 assembly shipping containers in water at 20 °C, with BPRA, steel, and no rods

is that the k_{eff} must be less then 1 0 with no soluble boron. The second is that k_{eff} must be less then 0 95 with soluble boron. The spent fuel pool was modeled with and without 500 ppm boron and also with and without the addition of BPRAs in the fresh fuel assemblies The results of the spent fuel pool calculations are shown in Figure 2-12 and Tables B-260 through B-263 of Appendix B For the 1[st] criterion, the spent fuel pool would be limited to 8-wt% U^{235} or less without the use of BPRAs The 2[nd] criterion limits the pool to 9 5-wt% U^{235} or less The addition of BPRAs would increase the limits of both criteria to 20-wt% U^{235}

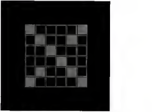

Figure 2-11 Top view of MCNP5 mpi model of a spent fuel pool

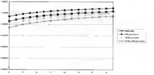

Figure 2-12. Results of MCNP5 mpi models of a spent fuel pool

CHAPTER 3
BATCH AND BURNUP CALCULATIONS FOR SPECIFIC CYCLE LENGTHS

CASMO-3 and CASFIND-6 Codes

In order to develop a model to be used to examine the feasibility and the cost impact of increasing fuel enrichments in the range of 5 to 10 wt% U^{235}, burnup and batch sizes for each enrichment and cycle length must be calculated. These variables are used in determining the final fuel cycle costs. A batch is a group of assemblies, composed of the same fuel type and enrichment, entering and leaving the reactor at the same time. Burnup is the power produced per amount of fuel used and for the purpose of this analysis is expressed as gigawatt-days per metric ton of uranium (GWd/mtU).

Discharge burnups for the various fuel cycles were determined using the CASMO-3 and CASFIND-6 codes. CASMO-3 is a two-dimensional transport theory code used for burnup calculations on BWR and PWR fuel assemblies [21]. CASMO-3 calculates the two-dimensional neutron and gamma flux distributions and isotopic compositions versus burnup within fuel assemblies using high order transport theory models. The program calculates the nuclear properties of the fuel in the core in order to generate neutronics data banks to be used by three-dimensional core simulators. CASMO-3 can also be used for criticality analysis and the calculation of isotopic inventory in depleted fuel.

The CASFIND-6 code was developed by Mr. M. Waters as part of his research work at the University of Florida. CASFIND-6 was written in FORTRAN-77 and has been designed to extract information from CASMO-3 outputs and to perform various calculations to determine discharge burnups, the time fuel is in core, isotopic wt% of spent fuel, and fuel cycle costs. The program utilizes a subroutine that uses the Least Mean Squares Method to determine the quadratic equation that represents the behavior of k_{eff} vs burnup. The method of Least Mean Squares states that the line represented by the equation should be fitted through the given points so that the sum of the squares of the distances of those points from the line is a minimum [22]. The following equation [23] is used:

$$\text{minimize over } a_1 \ldots a_M \quad \sum_{i}^{N}[y_i - y(x_i; a_1 \ldots a_M)]^2 \qquad (3\text{-}1)$$

The model used to represent the relationship of k_{eff} vs. burnup is a quadratic equation of the form

$$k_{eff} = a_0 + a_1{*}B + a_2{*}B^2 \qquad (3\text{-}2)$$

where a_0, a_1, and a_2 are weighting functions and B is the burnup.

Three equations are generated by setting the first derivative equal to zero with respect to the weights. These three equations are then solved with Cramers rule to determine the coefficients a_0, a_1, and a_2. The discharge burnup is then calculated using the fitted equation.

Batch and Burnup Results

A typical 17x17 PWR assembly with varying enrichments from 5.0 to 10.0% U^{235} was modeled and entered into CASMO-3. The outputs from CASMO-3 were entered into CASFIND-6 to determine core burnups and cycle lengths for the fuel. CASFIND-6

only determines the burnup and cycle length for a whole number of batches The burnup and cycle times were determined for the varying enrichments and are presented in Figures 3-1 and 3-2. These data were entered into EXCEL and linear interpolation was used to determine the number of batches required and the corresponding burnup Two sets of outage lengths were used, a 15-day outage length, typical of Exelon outages and a 30-day outage, which is the current average All PWR's in the United States are currently either using the 18 or 24-month cycle. The shutdown time is determined to coincide with the replacement power costs being the cheapest Data were calculated for the 12, 18, 24, 30, 36, and 42 month cycles The cycle length includes the outage time. The results of these calculations are presented in Figures 3-1 and 3-2 and in Appendix D in Tables D-1 through D-4 These results will be used to determine fuel cycle costs

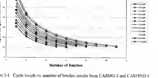

Figure 3-1 Cycle length vs. number of batches results from CASMO-3 and CASFIND 6

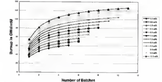

Figure 3-2 Burnup vs. number of batches results from CASMO-3 and CASFIND-6

CHAPTER 4
ECONOMIC MODEL OF THE NUCLEAR FUEL CYCLE

Overview of Economic Model

In order for increased enrichments to be economically feasible, the increased costs due to licensing, modification and replacement of equipment due to criticality issues must not outweigh the potential cost savings from higher burnups, smaller batch sizes, and construction of fewer dry cask storage units. The effects of potential variations in individual fuel cycle costs on potential cost savings or losses must be examined. An economic model was developed to determine feasibility and the cost impact of increasing fuel enrichments in the range of 5 to 10-wt% U^{235} under a base set of conditions. The model has the capability of varying the individual fuel cycle costs to determine not only if increasing enrichment is viable under current economic conditions, but also under any combination of increases or decreases of individual fuel cycle costs or interest rates. The fuel cycle costs included the following: 1) The natural uranium feed charges, 2) the conversion charge, 3) the separative work charge, 4) the fabrication charge, which includes a charge for the inclusion of stainless steel rods in the guide thimbles at enrichments greater then 5-wt% and the replacement of the steel rods with BPRAs at enrichments greater then 6.5-wt%, 5) a charge for replacement of the calciner at enrichments greater the 5-wt% and the replacement of the dry conversion kiln at enrichments greater then 8-wt%, both replacements are required due to criticality issues documented in Chapter 2, 6) a cost penalty for licensing the 30B container, the

fabrication facility, and the spent fuel pool for enrichments greater then 5-wt% U^{235} fuel, 7) the cost of licensing the reload fuel report, 8) an in-core capital use charge 9) a charge for the construction of dry cask storage units for spent fuel assemblies, 10) the current 1 $\frac{mil}{kW \cdot hr_e}$ fee for final fuel disposal cost, and 11) replacement power and maintenance costs during outage times

Start Cost Calculations

The start (front-end) cost (S_c) includes the cost of the ore, conversion, enrichment, fabrication (including a cost penalty associated with the addition of stainless steel or burnable poison rods to offset criticality issues of assemblies with greater then 5-wt% U^{235} fuel), the costs of new equipment and licensing for higher enrichments at the fabrication facility, and the cost of reload licensing. The natural uranium base feed cost was set to $40 per kilogram of uranium [24]. The total uranium feed charge ($TUFC$) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-1.

$$TUFC = (1+F_l)\cdot(1+C_l)\cdot\left(\frac{x_p - x_w}{x_f - x_w}\right)\cdot FP\cdot\left(1+\frac{i}{12}\right)^{Upy}\cdot\left(1-\frac{OL}{C_{ld}}\right)\cdot\left(\frac{1}{24\cdot brn\cdot eff}\right) \quad (4\text{-}1)$$

F_l is the fabrication loss (0.015), C_l is the uranium conversion loss (0.005), x_p is the desired enrichment, x_w is the tails enrichment (0.0025), x_f is the feed enrichment (0.00711), FP is the price of the feed in dollars per kilogram, i is the interest rate used to purchase the fuel, Upy is the payment schedule for the fuel (24 months is assumed), OL is the outage length in days (30 days is assumed for both the 18 and 24-month cycle), C_{ld} is the cycle length in days, brn is the burnup in GWd/mtU and an efficiency (eff) of 0.33 was assumed.

The initial price for uranium conversion was set at $7 per kilogram of uranium [25]. The conversion charge (*CC*) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-2.

$$CC = (1+F_1) \cdot (\frac{x_p - x_w}{x_f - x_w}) \cdot CP \cdot (1+\frac{i1}{12})^{Cpy} \cdot (1-\frac{OL}{C_M}) \cdot (\frac{1}{24 \cdot brn \cdot eff}) \qquad (4\text{-}2)$$

CP is the price of the conversion in dollars per kilogram and *Cpy* is the payment schedule for the conversion, assumed to be 18 months.

The base cost of a separative work unit (SWU) was set to $110 per SWU [26]. The number of SWUs needed for the desired enrichment per kilogram of product was calculated as shown in Equation 4-3 [3].

$$SWU = V(x_p) + \frac{W}{P} \cdot V(x_w) - \frac{F}{P} \cdot V(x_f) \qquad (4\text{-}3)$$

W is the number of kilograms of uranium in the waste stream (tails). *P* is the number of kilograms of enriched product, and *F* is the number of kilograms of feed material. The quantities $V(x_i)$ are known as separation potentials and are calculated as shown in Equation 4-4.

$$V(x_i) = (2 \cdot x_i - 1) \cdot \ln(\frac{x_i}{1-x_i}) \qquad (4\text{-}4)$$

Once the number of SWUs was determined, the enrichment charge (EC) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-5.

$$EC = SWU \cdot (1+F_1) \cdot SC \cdot (1+\frac{i1}{12})^{Spy} \cdot (1-\frac{OL}{C_M}) \cdot (\frac{1}{24 \cdot brn \cdot eff}) \qquad (4\text{-}5)$$

SC is the cost per SWU and the payment schedule for the enrichment (*Epy*) was assumed to be 12 months.

A base cost of 250 dollars per kilogram (J. Malone, Exelon, personal communication, April, 2003) was assigned for fabrication (FBC). An additional charge of $3.84 (multiplied by 0.5) per kilogram was included for enrichments greater than 5-wt% up to and including 6.5-wt% for the inclusion of stainless steel rods in half of the assemblies in order to ship and store fuel assemblies. For all enrichments there was an inclusion of $28.79 per kilogram for the additional cost of BPRAs for half of the assemblies in a batch (R. Szollosy, Southern Nuclear Operating Company, personal communication, April 12, 2004). This charge was increased to $57.58 per kilogram and the $3.84 per kilogram dropped for enrichments greater than 6.5-wt% due to the need to replace the steel rods with BPRAs in all the assemblies for criticality limitations discussed in Chapter 2 in the fabrication, shipment, and storage of new assemblies. The fabrication charge (*FC*) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-6

$$FC = FBC \cdot (1+\frac{i1}{12})^{Fpy} \cdot (1-\frac{OL}{C_u}) \cdot (\frac{1}{24 \cdot hrn \cdot eff}) \quad (4\text{-}6)$$

A payment schedule for the fabrication (*Fpy*) of 6 months was assumed.

The model utilized the dry fabrication process typified by the Richland plant of Areva/Framatome-ANP. There is little incentive for a fuel fabricator to encourage utilities to increase enrichments. Greater enrichments require smaller batch sizes and thus fewer assemblies to be built. Going from 5-wt% to 6-wt% for a utility using a two year cycle could result in a 33% reduction in the number of fuel assemblies purchased. Westinghouse, which holds the majority of PWR fuel fabrication contracts in the United

States, uses a wet process to convert the UF_6 gas to powder. For Westinghouse to increase enrichment would require either immediate replacement of much of the piping or scrapping the wet process altogether and going to the simpler one step process by the purchase of a dry conversion kiln. It is probable that any consortium of utilities that contracted Westinghouse to go to higher enrichments would be expected to carry the financial burden for the cleanup and disposal of the wet processing equipment. Areva/Framatome-ANP's dry conversion process does not appear to require any major equipment changes until the required enrichment is greater then 8 wt%, then their current dry conversion kiln would have to be replaced. Since Framatome has a much smaller fraction of the PWR fuel fabrication contracts, not only is far more likely they would be willing to undergo the financial risk of investing in any modifications and licensing costs for the fabrication of greater then 5-wt% U^{235} fuel in return for additional fuel fabrication contracts, but it is probable that the pricing of these contracts would be more competitive.

The total cost to the fabrication facility (T_{EU}) for the equipment upgrade was calculated as shown in Equation 4-7

$$T_{EU} = EU\left(1+\frac{i2}{12}\right)^{y\cdot 12} \qquad (4\text{-}7)$$

EU is the base cost of equipment replacement, $i2$ is the interest rate the fabrication plant uses on the loan taken out to pay for the upgrades and y is the number of years a loan is taken out to repay for these costs. The base interest rate used was 16% (in order to include a profit for the fabrication company) and the number of years was set to 5. A base cost of $350,000 for replacement of the calciner (D. Dahlstrom, ALSTOM, personal communication May 21, 2004) was included at enrichments greater then 5 wt% U^{235} and $500,000 was charged for replacement of the dry conversion kiln at enrichments greater

then 8-wt%. The charge to the utilities for the equipment replacement (C_{EU}) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-8.

$$C_{EU} = \left(\frac{T_{EU} \cdot C_l \cdot b \cdot (1+\frac{i1}{12})^{m}}{y \cdot c_{load} \cdot n_a}\right) \left(1-\frac{OL}{C_M}\right) \left(\frac{1}{24 \cdot hrs \cdot eff}\right) \quad (4\text{-}8)$$

C_l is the cycle length, b is the number of batches, m is the number of months the assemblies are ordered before they are used, c_{load} is the amount of fuel in the core and n_a is the number of power plants involved in the upgrades. This charge would be typically on the order of .01% of the fuel cycle cost. An additional cost of \$12 million in order to clean up Westinghouse's wet processing facility and switch over to a dry process [18] would still represent only 0.4% of the total fuel cycle cost.

The total cost to the facility (T_{LE}) for licensing the 30B containers for enrichments greater then 5-wt% was calculated as shown in Equation 4-9.

$$T_{LE} = LE \cdot \left(1+\frac{i}{12}\right)^{n \cdot 12} \quad (4\text{-}9)$$

LE, the sum of the licensing costs, was calculated to be \$158,700. The base interest rate used was 16% (to include profit for the enrichment plant licensing the containers) and the number of years was set to 5. A breakdown of the licensing and review costs is given in Table 4-1 and Table 4-2 [18].

Table 4-1 Cost estimates for licensing of the 30B container for greater than 5-wt% fuel

Type of Analysis	Estimated Manhours	Cost
Criticality Analysis	700	\$105,000
Environmental Protection	80	\$12,000
Radiation Protection	40	\$6,000
Risk Analysis	100	\$15,000

Table 4-2. Cost estimates for a 3 person NRC review of the 30B container for greater than 5-wt% fuel

Expense Type	Cost per Person	Total Cost
Airfare	$500	$1,500
Lodging/Food	$400	$1 200
Labor	$6,000	$18,000

The charge to the utilities for licensing the 30B containers for enrichments greater then 5-wt% (C_{LB}) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-10

$$C_{LB} = \left(\frac{T_{LB} \cdot C_1 \cdot b \cdot (1+F_i) \cdot (1+\frac{i1}{12})^{LB_{pp}}}{y \cdot c_{load} \cdot n_u}\right) \cdot (1 - \frac{OL}{C_{bl}}) \cdot (\frac{1}{24 \cdot hrs \cdot eff}) \quad (4\text{-}10)$$

The payment schedule for the licensing (LB_{pp}) for the base model was assumed to be at the time the enriched UF_6 was to be ordered, which is 12 months The base model assumes the 30B container is licensed by USEC during the construction of their gas centrifuge plant and the cost is passed on to the utilities In the case in which the utilities do not bear the burden, T_{LB} would be set to 0 If the fuel fabricator bears the burden of relicensing the 30B containers and must pass through this cost, Lb_{pp} would be set to 6 months. This charge would be typically in the order of .01% of the fuel cycle cost

The total cost to the fabrication facility (T_{LF}) for the licensing costs to process fuel enrichments greater then 5-wt% was calculated as shown in Equation 4-11

$$T_{LF} = LF \cdot \left(1 + \frac{i2}{i3}\right)^{i3} \quad (4\text{-}11)$$

LF, the sum of the licensing costs, was calculated to be $472 800 The base interest rate, i2, used was 16% and the number of years was set to 5 A breakdown of the licensing and review costs are given in Table 4-3 and Table 4-4 [18]

Table 4-3 Cost estimates for licensing of a fuel fabrication facility to process greater than 5-wt% fuel

Type of Analysis	Estimated Manhours	Cost
Criticality	2000	$300,000
Environmental Protection	80	$12,000
Radiation protection	40	$6,000
Risk Analysis	320	$48,000
Public hearings	160	$24,000

Table 4-4 Cost estimates for four visits of a 3 person NRC review of a fuel fabrication plant to process greater than 5-wt% fuel

Expense Type	Cost per Person	Total Cost
Airfare	$2,000	$6,000
Lodging/Food	$1,600	$4,800
Labor	$24,000	$72,000

The charge to the utilities for licensing the fabrication facility for enrichments greater then 5-wt% (C_{LF}) in $\frac{mils}{kW\ hr_e}$ was calculated as shown in Equation 4-12

$$C_{LF} = \left(\frac{T_{LF}\ C_i\ b\ (1+\frac{i1}{12})^{Tm}}{y\ c_{load}\ n_e}\right)\left(1-\frac{OL}{C_M}\right)\left(\frac{1}{24\ brn\ eff}\right) \qquad (4\text{-}12)$$

This charge is typically on the order of .02 to 0.03% of the fuel cycle cost

The reload licensing cost (R_l) in $\frac{mils}{kW\ hr_e}$ was calculated as shown in Equation 4-13

$$R_l = \frac{R_{lc}\ b\ (1+\frac{i1}{12})^{m}}{c_{load}\ 1000}\left(1-\frac{OL}{C_M}\right)\left(\frac{1}{24\ brn\ eff}\right) \qquad (4\text{-}13)$$

R_{lc} is the base cost of reload licensing, which was set to 1 million dollars (J. Malone Exelon, personal communication, April, 2003). The start (front-end) cost (S_c) was then calaulated as shown in Equation 4-14

$$S_c = TUFC + CC + EC + FC + C_{(t)} + C_{LR} + C_{LF} + R_f \quad (4\text{-}14)$$

In-Core Capital Use Charge, Storage, and Disposal Charge Calculations

The in-core capital use charge (ICC) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-15

$$ICC = ((fa \cdot (\frac{S_c}{2}\ (1+\tfrac{i}{12})^{ICT_a} - \frac{S_c}{2})) + (fb\ (\frac{S_c}{2}\ (1+\tfrac{i}{12})^{ICT_b} - \frac{S_c}{2})))$$

$$(1 - \frac{OL}{C_M}) \cdot (\frac{1}{24\ brn\ eff}) \quad (4\text{-}15)$$

The variables *fa* and *fb* are the corresponding fractions of the number of assemblies which with the upper and lower bounds for the lengths of time in months the fuel is in the core, *ICTa* and *ICTb* for a specific cycle length. For example, if enrichment x used 2.4 batches to reach a two-year cycle, 40% of the assemblies would be in the core for 3 cycles and *fa* would be 0.4. *ICTa* would be 3 times 24 months for a total of 72 months. *ICTb* would be 48 months and *fb* would be 0.6.

The cost of licensing the spent fuel (SL_c) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-16

$$SL_c = (\frac{BSLc \cdot C_f \cdot b}{y \cdot c_{load}})\ (1 - \frac{OL}{C_M})\ (\frac{1}{24\ brn\ eff}) \quad (4\text{-}16)$$

BSLc is the base cost of licensing spent fuel pool for enrichments beyond 5-wt% U^{235}. A summary of calculations of these costs is given in Tables 4-5 and 4-6.

The disposal fee (DF) in $\frac{mils}{kW \cdot hr_e}$ was calculated as shown in Equation 4-17

Table 4-5 Cost estimates for licensing of a spent fuel pool to store greater than 5-wt% fuel

Type of Analysis	Estimated Manhours	Cost
Criticality Analysis	350	$52,500
Environmental Protection	80	$12,000
Radiation Protection	40	$6,000
Risk Analysis	100	$15,000

Table 4-6 Cost estimates for a 3 person NRC review of a spent fuel pool for the storage of greater than 5 wt% fuel

Expense Type	Cost per Person	Total Cost
Airfare	$500	$1,500
Lodging/Food	$400	$1,200
Labor	$6,000	$18,000

$$DF = BDF \ (1-\frac{OL}{C_M}) \quad (4\text{-}17)$$

BDF is the base government charge to utilities of $1\,\frac{mil}{kW \ \ hr_e}$ for the final disposal of nuclear fuel [27] The dry cask storage cost ($DCSC$) was calculated as shown in Equation 4-18

$$DCSC = \frac{\$100\text{ per kg}}{24 \ \ eff \ \ hrn} \ (1-\frac{OL}{C_M}) \quad (4\text{-}18)$$

A recent court case indicates that the dry cask storage charges may be picked up by the Department of Energy This decision would transfer the cost savings from Equation 4-18 to the Department of Energy

Replacement Power and Fuel Cycle Cost Calculations

The replacement power (RP) in $kW{\cdot}hr_e$ needed during the outage was calculated as shown in Equation 4-19

$$RP = TP \cdot eff \cdot 24 \cdot OL \cdot 1000 \quad (4\text{-}19)$$

TP is the thermal power, modeled as 3030.3 MW_{th} and OL is the outage length in days, which was assigned base values of 15 and 30 days [28]. The labor costs (LC) in mils during an outage was calculated as shown in Equation 4-20.

$$LC = CPD \cdot OL \cdot 1000 \qquad (4\text{-}20)$$

CPD is the cost per day and was assigned a base value of $666,670 (J. Malone, Exelon, personal communication, April, 2003). The outage cost (OC) in $\frac{mils}{kW \cdot hr_e}$ is calculated as shown in equation 4-21.

$$OC = \left(\frac{RP \cdot RPC + LC}{TP}\right)\left(\frac{OL}{C_{M}}\right) \qquad (4\text{-}21)$$

RPC is the replacement power cost, which is set at 25 $\frac{mils}{kW \cdot hr_e}$. The fuel cycle cost ($FCC$) in $\frac{mils}{kW \cdot hr_e}$ is calculated as shown in Equation 4-22.

$$FCC = S_c + ICC + SL_c + DF + DCSC + OC \qquad (4\text{-}22)$$

CHAPTER 5
RESULTS AND DISCUSSION

Base Model Case

For the base model case with a 15-day outage, the minimum fuel cycle cost is at 4.5-wt% for the 12-month cycle, 6.0-wt% for the 18-month cycle, 6.5-wt% for the 24-month cycle, 7.5-wt% for the 30-month cycle, 8.0-wt% for the 36-month cycle, and 9.0-wt% for the 42-month cycle. For the base model case with a 30-day outage, the minimum fuel cycle cost is at 4.5-wt% for the 12-month cycle, 5.5-wt% for the 18-month cycle, 6.5-wt% for the 24-month cycle, 7.5-wt% for the 30-month cycle, 7.5-wt% for the 36-month cycle, and 9.0-wt% for the 42-month cycle. The cost savings or penalty in dollars per year per 1000 MW_e plant is determined by multiplying the difference fuel cycle cost in $\frac{mils}{kW \cdot hr_e}$ between two enrichments by a factor of 8.76×10^6. Assuming a 15-day outage length, the savings in fuel cycle costs in going from 5-wt% to 6.0-wt% for plants on an 18-month cycle is only \$91,000 a year per 1000 MW_e plant. If this outage length is increased to 30 days, the cost savings is reduced to \$13,000 a year. For the 24-month cycle with 15-day outages, the savings in fuel cycle costs in going from 5-wt% to 6.5-wt% is 0.182 $\frac{mils}{kW \cdot hr_e}$, approximately \$1,595,000 a year per 1000 MW_e plant. An increase of outage length to 30 days would decrease the cost savings to \$1,319,000 per year. A nuclear plant using a 30-month cycle with a 15-day outage would save

$5,072,000 per year by going from 5.0 wt% to 7.5-wt%. For a 30-day outage the savings would decrease to $4,545,000 per year. The 12-month cycle has a fuel cycle cost minimum below the currently licensed 5-wt% enrichment limit and is not competitive under the base model conditions. The 36 and 42 month cycles can not be achieved using 5-wt% fuel and therefore no cost savings are calculated.

All previous costs are calculated for the first five-year period in which the plants would have to pay for the licensing and equipment modifications to process and receive greater than 5 wt% fuel. After the first five years, 18 month cycle plants with 15-day outage lengths would save $140,000 per year by increasing their enrichment from 5.0-wt% to 6.0-wt%. An outage length of 30 days would decrease the savings to $93,000 per year. Plants on a 24-month cycle with 15-day outage lengths would save $1,710,000 per year by increasing their enrichment from 5.0 wt% to 6.5-wt%. This amount is decreased to $1,399,000 per year if the outage length is increased to 30 days. A 30 month cycle plant with a 15-day outage would save $5,155,000 per year by increasing its enrichment from 5.0-wt% to 7.5-wt%. A 30-day outage would lower this savings to $4,627,000 per year. The results for the base case calculations are presented in Figures 5-1 through 5-4 and in Tables E-1 and E-2.

Effect of Variation in Participating Number of Nuclear Plants

Variations in the number of nuclear plants which participate in a program for increasing fuel enrichments will affect the charges to each plant for the licensing and equipment replacement at the fabrication facility. If the number of participating plants is

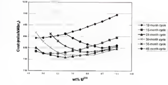

Figure 5-1 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years

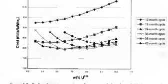

Figure 5 2 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years

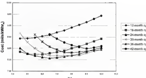

Figure 5-3 Fuel cycle cost comparison of varying cycle lengths with 15-day outage after the first 5 years

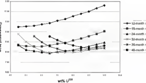

Figure 5-4 Fuel cycle cost comparison of varying cycle lengths with 30-day outage after the first 5 years

increased to 15, the savings for reactors for the first 5 years on a 30-month cycle with a 15-day outage changing from 5-wt% to 7.5-wt% fuel would increase by 0.3% to $5,088,000 a year for each plant. For the 24-month cycle, changing from 5 wt% to 6.5-wt% fuel would increase savings to approximately $1,610,000, (0.9%) and the 18-month cycle plants would only increase savings to $106,000 (16.4%) per year each. Increasing the number of participating plants from 15 to 20 only increases the cost savings to $5,095,000 (0.4%) a year per each 30-month cycle plant, $1,617,000 (1.4%) for 24-month cycle plants and $113,000 (23.6%) for the 18-month cycle. The savings for reactors on a 30-month cycle and 30-day outages would increase to $4,560,000 (0.3%) per year if the number of participating plants were increased from 10 to 15. The 24-month cycle would increase to $1,334,000 (1.1%) and the 18-month cycle plants would increase to $27,000 (117.8%). If the number of participating plants were increased to 20, the cost savings would increase to $4,568,000 (0.5%), $1,340,000 (1.6%), and $34,000 (169.9%) for the 30-month, 24-month, and 18-month cycle plants respectively. Increasing the number of participating plants beyond this point results in diminishing returns. In general, increasing the number of plants by five beyond 15 results in an increase of profits of approximately 50% of that seen by the previous increase of 5.

If the number of plants is decreased from the base model of 10 to 5, the 30-month cycle plants with 15-day outages would decrease savings to $5,010,000 (-1.2%), the 24-month cycle plants to $1,537,000 (-3.7%), and the 18-month cycle plants to $33,000 (-64.1%) per year. If the outage length is 30 days, the 30-month cycle plants savings would decrease to $4,483,000 (-1.4%) and the 24-month to $1,261,000 (-4.4%). The 18-month cycle's minimum fuel cycle cost changes to 5 wt% and plants with this cycle

length would see a net loss of $46 000 (-461 2%) a year if they increased their enrichments to 5 5-wt%. If only two plants participate in an increased enrichment program each plant would see a net loss of $266,000 (-291 2%) per year going from 5-wt% to 6 0-wt% if they were only on an 18-month cycle with 15-day outages The same two plants could save $1,238 000 (22 4%) by increasing enrichments from 5 0-wt% to 6 5-wt% if they were on a 24-month cycle, or $4 696 000 (-7 4%) per year if they were using a 30-month cycle For 30-day outages, the 18-month cycle would lose $342,000 (2 815 4%) a year, the 24-month cycle would decrease savings to $963 000 (-27 0%), and the 30-month cycle would see a reduced savings to $4 167 000 (-8 3%) per year for the first 5 years If only one 15-day outage plant were to participate in an increased enrichment program, it would see a net loss of $1,173,000 (-1,385 9%) per year by going from 5 0-wt% to 6 0-wt% on an 18-month cycle, a reduced savings of $324,000 (79 3%) a year going from 5 0-wt% to 6.5-wt% on a 24-month cycle, and reduced savings to $3,739,000 (-26 3%) per year for plants using a 30-month cycle The same plant with a 30-day outage would experience a loss of $1,245,000 (9,974 7%) for the 18 month cycle, reduced savings to $55,000 (-95 8%) for the 24-month cycle, and a savings of $3,206 000 (29 5%) per year for the first 5 years for plants on a 30-month cycle The results of the calculations for varying the number of participating plants are shown in Tables E-5 through E-16 and Figures 5-5 through 5-16

Effect of Variations in Uranium Ore Prices

The price of uranium has shown significant variation over the last 12 years as displayed in Figure 5-17 [29] In the last 18 months it has increased from $19 to $32 65 per kilogram The base economic model projects a cost of $40 per kilogram. Figures 5-

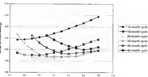

Figure 5-5 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with 15 participating reactors

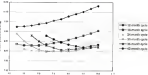

Figure 5-6 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with 15 participating reactors

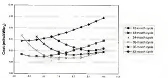

Figure 5-7 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with 20 participating reactors

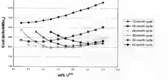

Figure 5-8. Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with 20 participating reactors

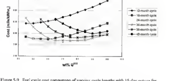

Figure 5-9 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with 25 participating reactors

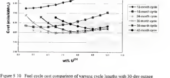

Figure 5-10 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with 25 participating reactors

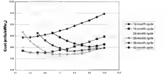

Figure 5-11 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with 5 participating reactors

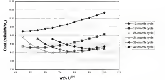

Figure 5-12 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with 5 participating reactors

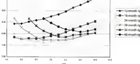

Figure 5-13 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with 2 participating reactors

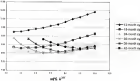

Figure 5-14 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with 2 participating reactors

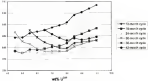

Figure 5-15 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with one participating reactor

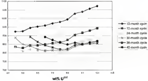

Figure 5-16 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with one participating reactor

19 through 5-57 show the individual fuel cycle costs for the various cycle lengths at 5.0 wt% as well as at their minimum fuel cycle cost enrichments. As shown in these figures the feed represents between 9% and 16% of the total fuel cycle costs. The percentage that the feed represents of the fuel cycle cost increases with longer cycle times and shorter outages. An increase of ore costs to $60 per kilogram would decrease cost savings to $72,000 (-21.0%) and $4,000 (-68.7%) a year per plant for the 18-month cycle with 15 and 30-day outage lengths. The cost savings for the 24-month cycle would increase to $1,747,000 (9.5%) and $1,437,000 (8.9%) for the 24-month cycle. The 30-month cycle plants would increase their cost savings to $5,660,000 (11.6%) and $5,067,000 (11.5%). A further increase to $80 a kilogram would result in a further reduction of cost savings to $53,000 (-42.1%) a year for 18-month cycle plants with 15-day outages. The 30-day outage plants would experience loss of $5,000 (-137.3%) a year. Reactors using 24-month cycle and 15-day and 30-day outages would increase savings to $1,899,000 (19.0%) and $1,555,000 (17.9%). The 30-month cycle plants would increase savings to $6,247,000 (23.2%) and $5,588,000 (22.0%) for 15 and 30-day outages, respectively. In general, for every $20 increase per kilogram from the $40 per kg base cost, the cost savings is reduced by $19,000 (-20.9%) and $9,000 (-69.2%) per year for 18-month cycle plants with 15 and 30-day outages, increased by $152,000 (9.5%) and $118,000 (8.9%) for 24-month cycle reactors, and increased by $588,000 (11.6%) and $521,000 (11.5%) per year for 30-month cycle plants. A reduction of ore costs from $40 to $20 a kilogram would result in equal but opposite change. The reason for the opposite trends for the 18-month cycle vs the 24 and 30-month cycles can shown by plotting a 2nd order polynomial trendline for the fuel cycle costs for the three cycles at

the base costs and at an increased feed cost of $80 per kilogram. The equations for the trendlines for the base costs with 15-day outages and the increased feed costs of $80 per kilogram are presented in Equations 5-1 through 5-6. Equations 5-7 through 5-12 are the 30-day outage calculations.

$$FCCT[15-day]_{18b} = 0.0339 \ enr^2 - 0.3682 \ enr + 8.7801 \quad (5\text{-}1)$$

$$FCCT[15-day]_{24b} = 0.0519 \ enr^2 - 0.7174 \ enr + 10.106 \quad (5\text{-}2)$$

$$FCCT[15-day]_{30b} = 0.0856 \ enr^2 - 1.3342 \ enr + 12.828 \quad (5\text{-}3)$$

$$FCCT[15-day]_{18f-80} = 0.04148 \ enr^2 - 0.4462 \ enr + 10.139 \quad (5\text{-}4)$$

$$FCCT[15-day]_{24f-80} = 0.0642 \ enr^2 - 0.8821 \ enr + 11.941 \quad (5\text{-}5)$$

$$FCCT[15-day]_{30f-80} = 0.1063 \ enr^2 - 1.6535 \ enr + 15.436 \quad (5\text{-}6)$$

$$FCCT[30-day]_{18b} = 0.0336 \ enr^2 - 0.3509 \ enr + 9.2165 \quad (5\text{-}7)$$

$$FCCT[30-day]_{24b} = 0.049 \ enr^2 - 0.6593 \ enr + 10.234 \quad (5\text{-}8)$$

$$FCCT[30-day]_{30b} = 0.0811 \ enr^2 - 1.2508 \ enr + 12.758 \quad (5\text{-}9)$$

$$FCCT[30-day]_{18f-80} = 0.0414 \ enr^2 - 0.425 \ enr + 10.521 \quad (5\text{-}10)$$

$$FCCT[30-day]_{24f-80} = 0.0606 \ enr^2 - 0.8098 \ enr + 11.978 \quad (5\text{-}11)$$

$$FCCT[30-day]_{30f-80} = 0.1007 \ enr^2 - 1.5494 \ enr + 15.249 \quad (5\text{-}12)$$

If the first three equations for the 15-day outages are differentiated and set to zero, the minimum for the 18-month cycle is 5.43-wt%, the 24-month is 6.91-wt% and the 30-month is 7.79-wt%. Equations 5-4 through 5-6 have minimums at 5.34-wt%, 6.87-wt%, and 7.78-wt%. In the case of the 18-month cycle, the base case actual minimum is lower than the proposed change to 6.0-wt%. For the 24 and 30-month cycles, the minimum for

the base case is higher than the proposed changes to 6 0 and 6 5-wt% respectively An increase in ore prices lowers the enrichment at which the fuel cycle cost is minimum for all three cycles, but is driving that enrichment away from the examined 18-month cycle minimum because it lies to the left of curve and in return drives it towards the proposed 24 and 30-month cycle enrichment changes. The same trends can be seen for the 30-day outage cycles. The minimums at the base cost of $40 per kilogram of ore are 5 22, 6 73, and 7 71-wt% for the 18, 24, and 30-month cycles When the ore cost is increased to $80 per kilogram, the minimum fuel cycle costs for the 18, 24, and 30-month cycles are at lower enrichments of 5 13, 6 68, and 7 69-wt% The results of fuel cycle cost calculations for varying uranium feed prices are presented in Figures 5-58 through 5-67 and in Tables E 17 through E-22 of Appendix E

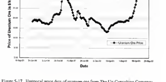

Figure 5-17 Historical price data of uranium ore from The Ux Consulting Company, LLC [28]

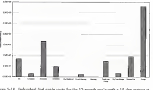

Figure 5-18 Individual fuel cycle costs for the 12-month cycle with a 15-day outage at 5.0 wt% U^{235} enrichment

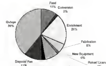

Figure 5-19 Individual fuel cycle cost percentages for the 12-month cycle with a 15-day outage at 5.0-wt% U^{235} enrichment

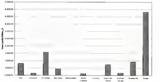

Figure 5-20 Individual fuel cycle costs for the 12-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

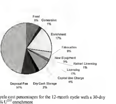

Figure 5-21 Individual fuel cycle cost percentages for the 12-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

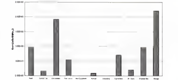

Figure 5-22 Individual fuel cycle costs for the 18-month cycle with a 15-day outage at 5 0-wt% U^{235} enrichment

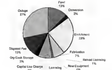

Figure 5-23 Individual fuel cycle cost percentages for the 18-month cycle with a 15-day outage at 5 0-wt% U^{235} enrichment

Figure 5-24 Individual fuel cycle costs for the 18-month cycle with a 30-day outage at 5 0-wt% U^{235} enrichment

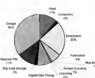

Figure 5-25 Individual fuel cycle cost percentages for the 18 month cycle with a 30-day outage at 5 0-wt% U^{235} enrichment

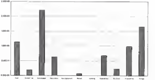

Figure 5-26 Individual fuel cycle costs for the 24-month cycle with a 15-day outage at 5 0-wt% U^{235} enrichment

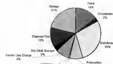

Figure 5-27 Individual fuel cycle cost percentages for the 24-month cycle with a 15-day outage at 5 0-wt% U^{235} enrichment

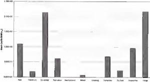

Figure 5-28 Individual fuel cycle costs for the 24-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

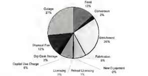

Figure 5-29 Individual fuel cycle cost percentages for the 24-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

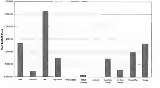

Figure 5-30 Individual fuel cycle costs for the 30-month cycle with a 15-day outage at 5.0-wt% U^{235} enrichment

Figure 5-31 Individual fuel cycle cost percentages for the 30-month cycle with a 15-day outage at 5.0-wt% U^{235} enrichment

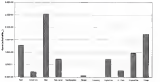

Figure 5-32 Individual fuel cycle costs for the 30-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

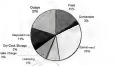

Figure 5-33 Individual fuel cycle cost percentages for the 30-month cycle with a 30-day outage at 5.0-wt% U^{235} enrichment

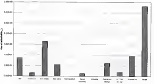

Figure 5-34 Individual fuel cycle costs for the 12-month cycle with a 15-day outage at 4 5-wt% U^{235} enrichment

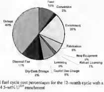

Figure 5-35 Individual fuel cycle cost percentages for the 12-month cycle with a 15-day outage at 4 5-wt% U^{235} enrichment

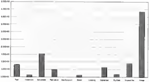

Figure 5-36 Individual fuel cycle costs for the 12-month cycle with a 30-day outage at 4.5-wt% U^{235} enrichment

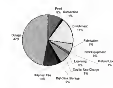

Figure 5-37 Individual fuel cycle cost percentages for the 12-month cycle with a 30-day outage at 4.5-wt% U^{235} enrichment

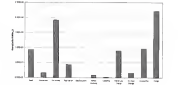

Figure 5-38 Individual fuel cycle costs for the 18-month cycle with a 15-day outage at 6.0-wt% U^{235} enrichment

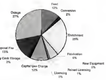

Figure 5-39 Individual fuel cycle cost percentages for the 18 month cycle with a 15-day outage at 6.0-wt% U^{235} enrichment

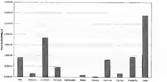

Figure 5-40 Individual fuel cycle costs for the 18-month cycle with a 30-day outage at 5 5-wt% U^{235} enrichment

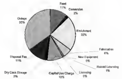

Figure 5-41 Individual fuel cycle cost percentages for the 18-month cycle with a 30-day outage at 5 5-wt% U^{235} enrichment

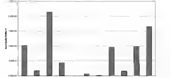

Figure 5-42. Individual fuel cycle costs for the 24-month cycle with a 15-day outage at 6.5-wt% U^{235} enrichment

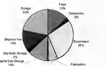

Figure 5-43 Individual fuel cycle cost percentages for the 24-month cycle with a 15-day outage at 6.5-wt% U^{235} enrichment

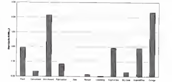

Figure 5-44 Individual fuel cycle costs for the 24-month cycle with a 30-day outage at 6.5-wt% U^{235} enrichment

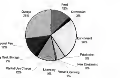

Figure 5-45 Individual fuel cycle cost percentages for the 24-month cycle with a 30-day outage at 6.5-wt% U^{235} enrichment

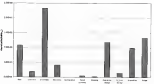

Figure 5-46 Individual fuel cycle costs for the 30-month cycle with a 15-day outage at 7.5 wt% U^{235} enrichment

Figure 5-47 Individual fuel cycle cost percentages for the 30-month cycle with a 15-day outage at 7.5 wt% U^{235} enrichment

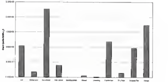

Figure 5-48 Individual fuel cycle costs for the 30-month cycle with a 30-day outage at 7 5-wt% U^{235} enrichment

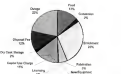

Figure 5-49 Individual fuel cycle cost percentages for the 30-month cycle with a 30-day outage at 7 5-wt% U^{235} enrichment

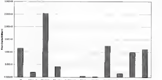

Figure 5-50 Individual fuel cycle costs for the 36 month cycle with a 15-day outage at 8 0-wt% U^{235} enrichment

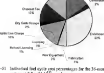

Figure 5-51 Individual fuel cycle cost percentages for the 36-month cycle with a 15-day outage at 8 0-wt% U^{235} enrichment

Figure 5-52 Individual fuel cycle costs for the 36-month cycle with a 30-day outage at 7.5-wt% U^{235} enrichment

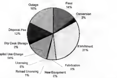

Figure 5-53 Individual fuel cycle cost percentages for the 36 month cycle with a 30-day outage at 7.5-wt% U^{235} enrichment

Figure 5-54 Individual fuel cycle costs for the 42-month cycle with a 15-day outage at 9 0-wt% U^{235} enrichment

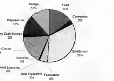

Figure 5-55 Individual fuel cycle cost percentages for the 42-month cycle with a 15-day outage at 9 0 wt% U^{235} enrichment

Figure 5-56 Individual fuel cycle costs for the 42-month cycle with a 30-day outage at 9.0-wt% U^{235} enrichment

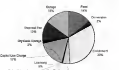

Figure 5-57 Individual fuel cycle cost percentages for the 42-month cycle with a 30-day outage at 9.0-wt% U^{235} enrichment

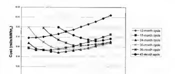

Figure 5-58 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with ore costs increased to $60 a kilogram

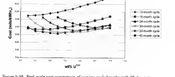

Figure 5-59 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with ore costs increased to $60 a kilogram

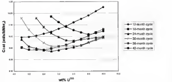

Figure 5-60 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with ore costs increased to \$80 a kilogram

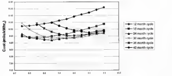

Figure 5-61 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with ore costs increased to \$80 a kilogram

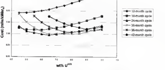

Figure 5-62 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with ore costs decreased to $20 a kilogram

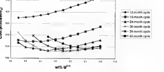

Figure 5-63 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with ore costs decreased to $20 a kilogram

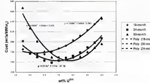

Figure 5-64 Base fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length

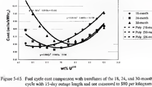

Figure 5-65 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and ore increased to $80 per kilogram

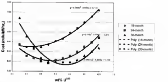

Figure 5-66 Base fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length

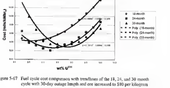

Figure 5-67 Fuel cycle cost comparison with trendlines of the 18, 24, and 30 month cycle with 30-day outage length and ore increased to $80 per kilogram

Effect of Variations in Conversion Prices

Over the last 10 years the price of conversion has varied from a low of $2.25 per kg in June of 2000 to the current price of $7.25 per kg [29]. The base economic model projects a cost of $7 per kilogram. As shown in Figure 5-18 through 5-57, the conversion process represents only 1 to 3% of the fuel cycle costs. An increase of conversion costs to $10 per kilogram would decrease cost savings to $88,000 (-3.0%) and $11,000 (-9.9%) a year per plant for the 18-month cycle with 15 and 30-day outage lengths. The cost savings for the 24-month cycle would increase to $1,617,000 (1.4%) and $1,337,000 (1.3%) for the 24-month cycle. The 30-month cycle plants would increase their cost savings to $5,157,000 (1.7%) and $5,620,000 (1.7%). A further increase to $13 a kilogram would result in a further reduction of cost savings to $85,000 (-6.1%) a year for 18-month cycle plants with 15-day outages. The 30-day outage plants would reduce savings to $10,000 (-19.8%) a year. Reactors using 24-month cycle and 15-day and 30-day outages would increase savings to $1,639,000 (2.7%) and $1,353,000 (2.6%). The 30-month cycle plants would increase savings to $5,241,000 (3.3%) and $4,695,000 (3.3%) for 15 and 30-day outages, respectively. In general, for every $3 increase per kilogram from the $7 per kilogram base cost, the cost savings is reduced by $3,000 (-3.0%) and $1,000 (-9.9%) per year for 18-month cycle plants with 15 and 30-day outages, increased by $22,000 (1.4%) and $18,000 (1.3%) for 24-month cycle reactors, and increased by $85,000 (1.7%) and $75,000 (1.7%) per year for 30-month cycle plants. A reduction of conversion costs from $10 to $7 a kilogram would result in equal but opposite changes. As with the feed cost variations, the reason for the opposite trends can shown by plotting a 2nd order polynomial trendline for the fuel cycle costs for

the three cycle lengths at an increased conversion cost of $13 per kilogram. The equations for the trendlines for the increased conversion cost of $13 per kilogram are presented in Equations 5-13 through 5-18

$$FCCT[15-day]_{18c=13} = 0.0351 \cdot enr^2 - 0.3795 \cdot enr + 8.976 \quad (5\text{-}13)$$

$$FCCT[15-day]_{24c=13} = 0.0537 \cdot enr^2 - 0.7411 \cdot enr + 10.370 \quad (5\text{-}14)$$

$$FCCT[15-day]_{30c=13} = 0.0886 \cdot enr^2 - 1.3802 \cdot enr + 13.204 \quad (5\text{-}15)$$

$$FCCT[30-day]_{18c=13} = 0.0347 \cdot enr^2 - 0.3616 \cdot enr + 9.4045 \quad (5\text{-}16)$$

$$FCCT[30-day]_{24c=13} = 0.0507 \cdot enr^2 - 0.681 \cdot enr + 10.485 \quad (5\text{-}17)$$

$$FCCT[30-day]_{30c=13} = 0.084 \cdot enr^2 - 1.2939 \cdot enr + 13.117 \quad (5\text{-}18)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 5.41-wt%, 6.90-wt% for the 24-month cycle, and 7.79-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5.21-wt%, 6.72-wt%, and 7.70-wt% for the 18, 24, and 30-month cycles. An increase in conversion prices lowers the enrichment at which the fuel cycle cost is minimum for all three cycles, but as with case of increased feed costs, the new minimum for the 18-month cycle is further away from the examined minimum because it lies to the left of curve. In the case of the 24 and 30-month cycles, the new minimum becomes closer to the original 6.5 and 7.5-wt% enrichment changes. The results of fuel cycle cost calculations for varying conversion prices are presented in Figures 5-68 through 5-75 and in Tables E-23 through E-28 of Appendix E.

Effect of Variations in Enrichment Prices

The price of SWUs in the United States has varied in the last 10 years from $80

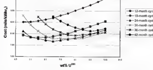

Figure 5-68 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with conversion costs increased to $10 a kilogram

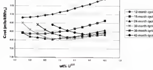

Figure 5-69 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with conversion costs increased to $10 a kilogram

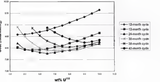

Figure 5-70 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with conversion costs increased to $13 a kilogram

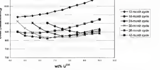

Figure 5-71 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with conversion costs increased to $13 a kilogram

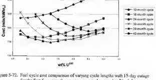

Figure 5-72. Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with conversion costs decreased to \$4 a kilogram

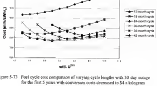

Figure 5-73 Fuel cycle cost comparison of varying cycle lengths with 30 day outage for the first 5 years with conversion costs decreased to \$4 a kilogram

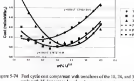

Figure 5-74 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and conversion costs increased to $13 per kilogram

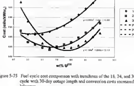

Figure 5-75 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and conversion costs increased to $13 per kilogram

per SWU to the current high of $108 per SWU [29] as shown in Figure 5-76. The base economic model used a value of $110 per SWU. Figures 5-18 through 5-57 show that enrichment ranges from 17% to 33% of the total fuel cycle costs. The percentages increase with longer cycle times and shorter outages. A decrease in price of SWU to $90 per SWU from the advent of a second enrichment facility built in the U.S. would increase cost savings to $283,000 (209.9%) and $111,000 (781.6%) a year per plant for the 18-month cycle with 15 and 30-day outage lengths if enrichments were increased to 6.0-wt% and 5.5-wt%, respectively. Decreases in the price of SWU of this magnitude increases the enrichment for minimum fuel cycle costs for the 30-day outage plants to 6.0-wt% from 5.5-wt%. Raising the enrichment to 6.0-wt% increases cost savings to $195,000 (1,449.7%) per year. The cost savings for the 24-month cycle would increase to $1,760,000 (10.3%) and $1,501,000 (13.8%) for the 24-month cycle. The 30-month cycle plants would increase their cost savings to $5,093,000 (0.4%) and $4,606,000 (1.3%). A further decrease to $80 a SWU would increase cost savings to $378,000 (314.8%) a year for 18-month cycle plants with 15-day outages. The 30-day outage plants would increase savings to $160,000 (1,172.4%) a year if they increased enrichments to 5.5-wt% and $293,000 (2,219.6%) if they used 6.0-w% fuel. Reactors using 24-month cycle and 15-day and 30-day outages would increase savings to $1,843,000 (15.5%) and $1,593,000 (20.7%). The 30 month cycle plants would increase savings to $5,104,000 (0.6%) and $4,636,000 (2.0%) for 15 and 30-day outages, respectively. In general, for every $10 decrease per SWU from the $110 per SWU base cost, the cost savings is increased by $96,000 (105.2%) and $49,000 (388.5%) ($98,000 (777.0%) if switching to 6.0-wt% instead of 5.5-wt%) per year for 18-month cycle plants with 15 and 30-day outages

increased by $83,000 (5.2%) and $91,000 (6.9%) for 24-month cycle reactors, and increased by $10,000 (0.2%) and $31,000 (0.7%) per year for 30-month cycle plants. An increase of SWU costs by $10 a SWU would result in equal but opposite changes. The results of fuel cycle cost calculations with varying SWU prices are presented in Figures 5-77 through 5-84 and Tables E-29 through E-36 of Appendix E.

A 2[nd] order polynomial trendline for the fuel cycle costs for the 18, 24, and 30-month cycles at a decreased SWU cost of $80 per SWU is presented in Figures 5-85 and 5-86. The equations for the trendlines for the decreased SWU cost of $80 per SWU are presented in Equations 5-19 through 5-24.

$$FCCT[15-day]_{18m=80} = 0.0314\ enr^2 - 0.3741\ enr + 8.2503 \qquad (5\text{-}19)$$

$$FCCT[15-day]_{24m=80} = 0.0475\ enr^2 - 0.6847\ enr + 9.3493 \qquad (5\text{-}20)$$

$$FCCT[15-day]_{30m=80} = 0.0772\ enr^2 - 1.2281\ enr + 11.691 \qquad (5\text{-}21)$$

$$FCCT[30-day]_{18m=80} = 0.031\ enr^2 - 0.3566\ enr + 8.7079 \qquad (5\text{-}22)$$

$$FCCT[30-day]_{24m=80} = 0.0448\ enr^2 - 0.6322\ enr + 9.5192 \qquad (5\text{-}23)$$

$$FCCT[30-day]_{30m=80} = 0.0732\ enr^2 - 1.154\ enr + 11.677 \qquad (5\text{-}24)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 5.96-wt%, 7.21-wt% for the 24-month cycle, and 7.95-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5.75-wt%, 7.06-wt%, and 7.88-wt% for the 18, 24, and 30 month cycles. A decrease in SWU cost raises the enrichment at which the fuel cycle cost is minimum for all three cycles.

In order to fully understand the impact of variation of the SWU costs, the individual fuel cycle costs are plotted in Figures 5-87 through 5-104. As shown in these

figures, the SWU charge using the base case model is one of the more dominate charges in the fuel cycle cost Not including outage costs, the in-core capital use charge becomes second only to the SWU charge at enrichments greater than 6 5-wt% for the 18-month cycle and 24-month cycles and at 7.0-wt% for the 30 month cycles The in-core capital use charge is very dependant on the cost of SWUs. Decreasing the SWU costs from $110 to $80 a SWU, lowers the slope of the plotted in-core capital use charge trendline from 0.2181 for the 18-month cycle, 0 2112 for the 24-month cycle, and 0.2040 for the 30-month cycle to 0 1800 0 1740, and 0 1678 for the respective cycle lengths using a 15-day outage. For plants with 30-day outages the slope is lowered from 0 2230 to 0 1841 for the 18-month cycle, from 0.2150 to 0 1772 for the 24-month cycle, and from 0.2058 to 0 1693 for the 30-month cycle. This also increases the enrichment value at which the in-core capital use charge begins to dominate over all other charges (excluding SWU and outage) by approximately 1 0-wt% for all three cycles.

The individual fuel cycle costs for the same relative decrease (27%) in feed costs from $40 to $29 are plotted in Figures 5-105 through 5-110 In this case the slopes of the plotted in-core capital use charge trendline is only lowered to 0 2026, 0 1960, and 0 1893 for the 18, 24, and 30-month cycles with 15-day outages. The slope is lowered to 0 2072, 0 1996, and 0 1910 for the 18, 24, and 30-month cycle plants with 30-day outages. A 27% decrease in SWU costs corresponds to a 17-18% decrease in the slope of the line for the in-core capital use charges while a similar decrease in uranium feed prices only lowers the slope by approximately 7% Table E-37 presents a listing of the individual fuel cycle contributors to the in-core capital use charge with the percent decrease in its slope for a corresponding 27% decrease in the contributor's base value

As shown in this table, the in-core capital use charge is strongly coupled to enrichment charges. This in-core capital use charge is the strongest contributor to the shape of fuel cycle costs curves, which in turn determines the enrichment at which the fuel cycle costs are at a minimum. Figures 5-111 through 5-134 present the individual fuel cycle costs for the 18, 24, and 30-month cycles with 15 and 30-day outages when the conversion costs, fabrication costs, reload licensing costs, and interest rates are reduced by 27%.

Figures 5-135 through 5-146 show the individual fuel cycle costs for the 18, 24, and 30-month cycles when the interest on fuel purchases is set to zero (eliminating the in-core capital use charge) and when the interest rate is increased to 20%. The corresponding fuel cycle cost graphs are shown in Figures 5-147 through 5-150. As shown in these figures, the shape is that of a parabola. Increasing the interest and thus the in-core capital use charge shifts the minimum to the left (lower enrichments) and tightens the parabola, increasing the slope of the endpoints, which would in turn increase the difference in price of fuel cycle costs as the enrichment is varied. A decrease in the in-core capital use charges shifts the minimum to the right (higher enrichments), decreasing the slope of the endpoints which decreases the relative change of fuel cycle costs as the enrichment is varied.

Effect of Variations in the Cost of Fabrication

A base value of $250 per kg for fabrication costs was used in the model. As shown in Figures 5-19 through 5-57, this typically represents 5 to 9% of the fuel cycle cost at the respective fuel cycle minimums. A 10% increase in fabrication costs increases cost savings for the 18, 24, and 30 month cycles with 15-day outages to $184,000 (102.0%), $1,744,000 (10.0%), and $5,340,000 (5.7%) a year if a switch is made from 5-

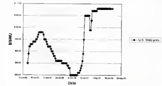

Figure 5-76. Historical price data of SWUs in the United States from The Ux Consulting Company, LLC [28]

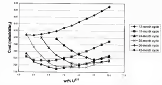

Figure 5-77 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost decreased to $90 a SWU

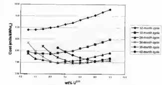

Figure 5-78 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost decreased to $90 a SWU

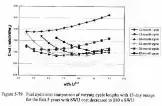

Figure 5-79 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost decreased to $80 a SWU

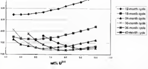

Figure 5-80 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost decreased to \$80 a SWU

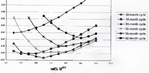

Figure 5-81 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost increased to \$130 a SWU

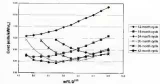

Figure 5-82 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost increased to \$130 a SWU

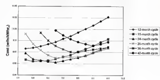

Figure 5-83 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost increased to \$150 a SWU

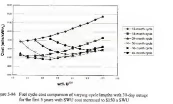

Figure 5-84 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost increased to $150 a SWU

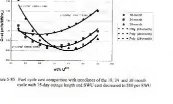

Figure 5-85 Fuel cycle cost comparison with trendlines of the 18, 24 and 30 month cycle with 15-day outage length and SWU cost decreased to $80 per SWU

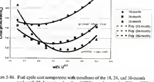

Figure 5-86. Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and SWU cost decreased to $80 per SWU

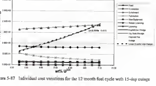

Figure 5-87 Individual cost variations for the 12-month fuel cycle with 15-day outage

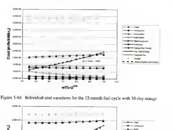

Figure 5-88 Individual cost variations for the 12-month fuel cycle with 30-day outage

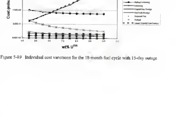

Figure 5-89 Individual cost variations for the 18-month fuel cycle with 15-day outage

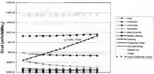

Figure 5-90. Individual cost variations for the 18-month fuel cycle with 30-day outage

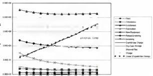

Figure 5-91. Individual cost variations for the 24-month fuel cycle with 15-day outage

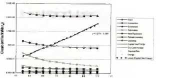

Figure 5-92. Individual cost variations for the 24-month fuel cycle with 30-day outage

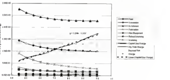

Figure 5-93 Individual cost variations for the 30-month fuel cycle with 15-day outage

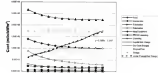

Figure 5-94 Individual cost variations for the 30-month fuel cycle with 30-day outage

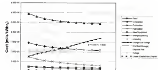

Figure 5-95 Individual cost variations for the 36-month fuel cycle with 15-day outage

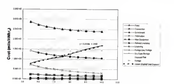

Figure 5-96 Individual cost variations for the 36-month fuel cycle with 30-day outage

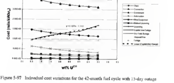

Figure 5-97 Individual cost variations for the 42-month fuel cycle with 15-day outage

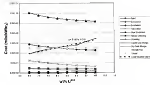

Figure 5 98 Individual cost variations for the 42-month fuel cycle with 30-day outage

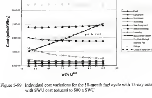

Figure 5-99 Individual cost variations for the 18-month fuel cycle with 15-day outage with SWU cost reduced to \$80 a SWU

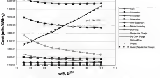

Figure 5-100 Individual cost variations for the 24-month fuel cycle with 15-day outage with SWU cost reduced to $50 a SWU

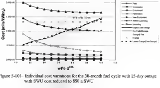

Figure 5-101 Individual cost variations for the 30-month fuel cycle with 15-day outage with SWU cost reduced to $50 a SWU

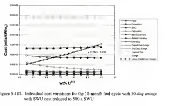

Figure 5-102. Individual cost variations for the 18-month fuel cycle with 30-day outage with SWU cost reduced to \$80 a SWU

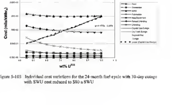

Figure 5-103 Individual cost variations for the 24-month fuel cycle with 30-day outage with SWU cost reduced to \$80 a SWU

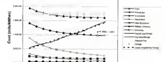

Figure 5-104 Individual cost variations for the 30 month fuel cycle with 30-day outage with SWU cost reduced to $80 a SWU

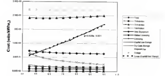

Figure 5-105 Individual cost variations for the 18-month fuel cycle with 15-day outage with ore cost reduced by 27%

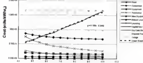

Figure 5-106 Individual cost variations for the 24-month fuel cycle with 15-day outage with ore cost reduced by 27%

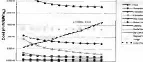

Figure 5-107 Individual cost variations for the 30-month fuel cycle with 15-day outage with ore cost reduced by 27%

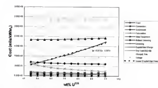

Figure 5-108 Individual cost variations for the 18-month fuel cycle with 30-day outage with ore cost reduced by 27%

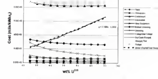

Figure 5-109 Individual cost variations for the 24-month fuel cycle with 30-day outage with ore cost reduced by 27%

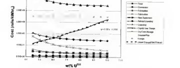

Figure 5-110 Individual cost variations for the 30-month fuel cycle with 30-day outage with ore cost reduced by 27%

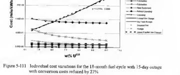

Figure 5-111 Individual cost variations for the 18-month fuel cycle with 15-day outage with conversion costs reduced by 27%

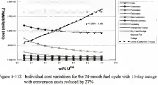

Figure 5-112 Individual cost variations for the 24-month fuel cycle with 15-day outage with conversion costs reduced by 27%

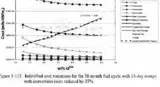

Figure 5-113 Individual cost variations for the 30-month fuel cycle with 15-day outage with conversion costs reduced by 27%

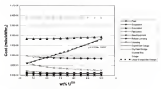

Figure 5-114 Individual cost variations for the 18-month fuel cycle with 30-day outage with conversion costs reduced by 27%

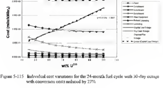

Figure 5-115 Individual cost variations for the 24-month fuel cycle with 30-day outage with conversion costs reduced by 27%

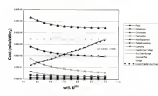

Figure 5-116 Individual cost variations for the 30-month fuel cycle with 30-day outage with conversion costs reduced by 27%

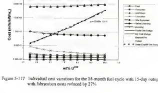

Figure 5-117 Individual cost variations for the 18-month fuel cycle with 15-day outage with fabrication costs reduced by 27%

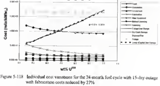

Figure 5-118 Individual cost variations for the 24-month fuel cycle with 15-day outage with fabrication costs reduced by 27%

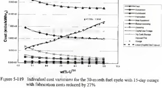

Figure 5-119 Individual cost variations for the 30-month fuel cycle with 15-day outage with fabrication costs reduced by 27%

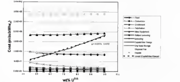

Figure 5-120 Individual cost variations for the 18-month fuel cycle with 30-day outage with fabrication costs reduced by 27%

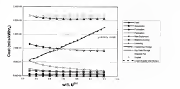

Figure 5-121 Individual cost variations for the 24-month fuel cycle with 30-day outage with fabrication costs reduced by 27%

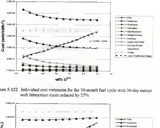

Figure 5-122 Individual cost variations for the 30-month fuel cycle with 30-day outage with fabrication costs reduced by 27%

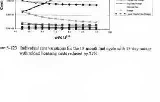

Figure 5-123 Individual cost variations for the 18 month fuel cycle with 15 day outage with reload licensing costs reduced by 27%

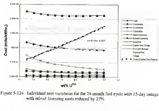

Figure 5-124 Individual cost variations for the 24-month fuel cycle with 15-day outage with reload licensing costs reduced by 27%

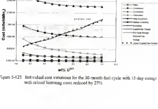

Figure 5-125 Individual cost variations for the 30-month fuel cycle with 15-day outage with reload licensing costs reduced by 27%

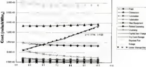

Figure 5-126 Individual cost variations for the 18-month fuel cycle with 30-day outage with reload licensing costs reduced by 27%

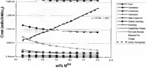

Figure 5-127 Individual cost variations for the 24-month fuel cycle with 30-day outage with reload licensing costs reduced by 27%

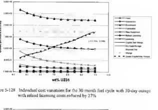

Figure 5-128 Individual cost variations for the 30-month fuel cycle with 30-day outage with reload licensing costs reduced by 27%

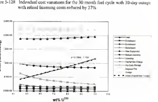

Figure 5-129 Individual cost variations for the 18-month fuel cycle with 15-day outage with interest rates for fuel purchases reduced by 27%

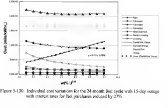

Figure 5-130. Individual cost variations for the 24-month fuel cycle with 15-day outage with interest rates for fuel purchases reduced by 27%

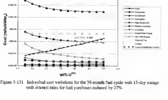

Figure 5-131 Individual cost variations for the 30-month fuel cycle with 15-day outage with interest rates for fuel purchases reduced by 27%

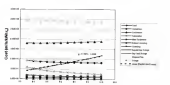

Figure 5-132. Individual cost variations for the 18-month fuel cycle with 30-day outage with interest rates for fuel purchases reduced by 27%

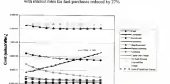

Figure 5-133 Individual cost variations for the 24-month fuel cycle with 30-day outage with interest rates for fuel purchases reduced by 27%

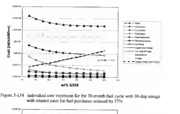

Figure 5-134 Individual cost variations for the 30-month fuel cycle with 30-day outage with interest rates for fuel purchases reduced by 27%

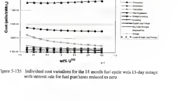

Figure 5-135 Individual cost variations for the 18 month fuel cycle with 15-day outage with interest rate for fuel purchases reduced to zero

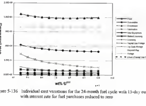

Figure 5-136 Individual cost variations for the 24-month fuel cycle with 15-day outage with interest rate for fuel purchases reduced to zero

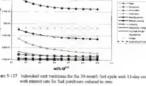

Figure 5-137 Individual cost variations for the 30-month fuel cycle with 15-day outage with interest rate for fuel purchases reduced to zero

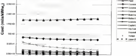

Figure 5-138 Individual cost variations for the 18-month fuel cycle with 30-day outage with interest rate for fuel purchases reduced to zero

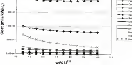

Figure 5-139 Individual cost variations for the 24-month fuel cycle with 30-day outage with interest rate for fuel purchases reduced to zero

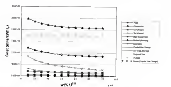

Figure 5-140 Individual cost variations for the 30-month fuel cycle with 30-day outage with interest rate for fuel purchases reduced to zero

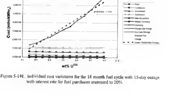

Figure 5-141 Individual cost variations for the 18 month fuel cycle with 15-day outage with interest rate for fuel purchases increased to 20%

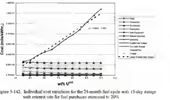

Figure 5-142. Individual cost variations for the 24-month fuel cycle with 15-day outage with interest rate for fuel purchases increased to 20%

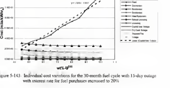

Figure 5-143. Individual cost variations for the 30-month fuel cycle with 15-day outage with interest rate for fuel purchases increased to 20%

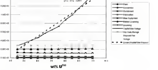

Figure 5-144 Individual cost variations for the 18-month fuel cycle with 30-day outage with interest rate for fuel purchases increased to 20%

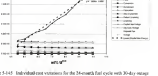

Figure 5-145 Individual cost variations for the 24-month fuel cycle with 30-day outage with interest rate for fuel purchases increased to 20%

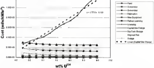

Figure 5-146 Individual cost variations for the 30-month fuel cycle with 30-day outage with interest rate for fuel purchases increased to 20%

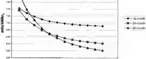

Figure 5-147 Fuel cycle cost comparison of the 18, 24, and 30-month cycles with 15-day outage length and interest rate on fuel purchases set to zero

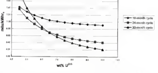

Figure 5-148 Fuel cycle cost comparison of the 18, 24, and 30-month cycles with 30-day outage length and interest rate on fuel purchases set to zero

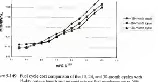

Figure 5-149 Fuel cycle cost comparison of the 18, 24, and 30-month cycles with 15-day outage length and interest rate on fuel purchases set to 20%

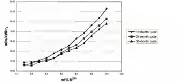

Figure 5-150 Fuel cycle cost comparison of the 18, 24, and 30-month cycles with 30-day outage length and interest rate on fuel purchases set to 20%

wt% to the respective enrichment minimums For the 30-day outage, the cost savings are increased to $91,000 (617 7%), $1,472,000 (11 6%), and $4,822,000 (6 1%) with the enrichment minimum for the 18-month cycle increasing to 6.0-wt% An increase of 20% in fabrication costs increases cost savings to $277,000 (204 0%), $1,915,000 (20 0%), and $5,648,000 (11 4%) per year for the 18, 24, and 30-month cycles with 15-day outages and $180,000 (1.325 7%), $1 625,000 (23 1%) and $5,099 000 (12.2%) per year for 30-day outages if a switch is made to the enrichment at which fuel cycle costs are a minimum for each respective case In general, for every 10% increase of fabrication costs, the cost savings are increased by $93 000 (102 0%) $149 000 (10 0%) and $288 000 (5 7%) per year for 18, 24, and 30-month cycles with 15-day outages For the 30-day outage plants the savings are increased by $50,000 (392.5%) for an increase to 5 5-wt% or $90,000 (617 7%) if 6 0-wt% instead of 5 5-wt% is chosen for the 18-month

cycle $153,000 (11 6%) for the 24-month cycle, and $277,000 (6 1%) per year for the 30-month cycle. Decreases of the same magnitude in fabrication costs would result in equal but opposite changes. The results from these calculations are presented in Figures 5-151 through 5-158 and in Tables E-29 through E-36 of Appendix E.

A 2[nd] order polynomial trendline for the fuel cycle costs for the 18, 24, and 30-month cycles with a 20% increase in fabrication costs is presented in Figures 5-159 and 5-160. The equations for the trendlines for increased fabrication costs are presented in Equations 5-25 through 5-30.

$$FCCT[15-day]_{18f+300} = 0.0363\ enr^2 - 0.4143\ enr + 9.0767 \quad (5\text{-}25)$$

$$FCCT[15-day]_{24f+300} = 0.0551\ enr^2 - 0.7785\ enr + 10.474 \quad (5\text{-}26)$$

$$FCCT[15-day]_{30f+300} = 0.0901\ enr^2 - 1.4187\ enr + 13.303 \quad (5\text{-}27)$$

$$FCCT[30-day]_{18f+300} = 0.0359\ enr^2 - 0.3949\ enr + 9.5013 \quad (5\text{-}28)$$

$$FCCT[30-day]_{24f+300} = 0.052\ enr^2 - 0.7174\ enr + 10.587 \quad (5\text{-}29)$$

$$FCCT[30-day]_{30f+300} = 0.0855\ enr^2 - 1.3318\ enr + 13.216 \quad (5\text{-}30)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 5 71-wt%, 7 06-wt% for the 24-month cycle, and 7 87-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5 50-wt%, 6 90-wt%, and 7 79-wt% for the 18, 24, and 30-month cycles. An increase in fabrication costs raises the enrichment at which the fuel cycle cost is minimum for all three cycles.

Effect of Variations in Reload Licensing Costs

A base cost of $1,000,000 for reload licensing was used in the model. As shown

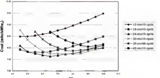

Figure 5-151 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fabrication costs increased by 10%

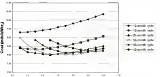

Figure 5-152 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fabrication costs increased by 10%

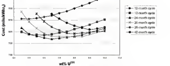

Figure 5-153 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fabrication costs increased by 20%

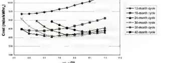

Figure 5-154 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fabrication costs increased by 20%

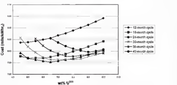

Figure 5-155 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fabrication costs decreased by 10%

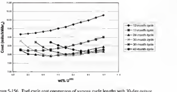

Figure 5-156 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fabrication costs decreased by 10%

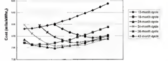

Figure 5-157 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fabrication costs decreased by 20%

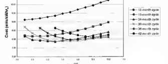

Figure 5-158 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fabricatson costs decreased by 20%

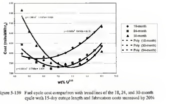

Figure 5-159 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and fabrication costs increased by 20%

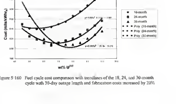

Figure 5-160 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fabrication costs increased by 20%

in Figures 5-19 though 5-57, this typically represents only 1% of the fuel cycle cost at the respective fuel cycle minimums. If reload licensing costs are decreased by 25%, cost savings for the 18, 24, and 30-month cycles with 15-day outages are increased to $103,000 (12.9%), $1,609,000 (0.8%), and $5,083,000 (0.2%) a year if a switch is made from 5-wt% to the respective enrichment minimums. Plants with a 30-day outage increase cost savings to $20,000 (56.1%), $1,334,000 (1.1%), and $4,557,000 (0.3%) per year. A 50% decrease in reload licensing costs increases the cost savings to $115,000 (25.8%), $1,622,000 (1.7%), and $5,094,000 (0.5%) per year for 15-day outages. Plants with 30-day outages would increase cost savings to $28,000 (112.1%), $1,348,000 (2.2%), and $4,568,000 (0.5%) per year. In general, for every 25% decrease in reload licensing costs, the costs savings for 15-day outage plants are increased by $12,000 (12.9%), $13,000 (0.8%), and $11,000 (0.2%) for the 18, 24, and 30 month cycles. Plants with 30-day outages would increase their savings by $8,000 (56.1%), $14,000 (1.1%), and $11,000 (0.3%). Increases to the reload licensing costs of the same magnitude would have equal but opposite changes. The results from these calculations are presented in Figures 5-161 through 5-168 and in Tables E-46 through E-53 of Appendix E.

A 2nd order polynomial trendline for the fuel cycle costs for the 18, 24, and 30-month cycles with an increase of 50% in reload licensing costs is presented in Figures 5-169 and 5-170. The equations for the trendlines for a 50% increase in reload licensing costs are presented in Equations 5-31 through 5-36.

$$FCCT[15-day]_{18,rl=1.5e6} = 0.034\ enr^2 - 0.367\ enr + 8.8214 \quad (5\text{-}31)$$

$$FCCT[15-day]_{24,rl=1.5e6} = 0.052\ enr^2 - 0.7167\ enr + 10.137 \quad (5\text{-}32)$$

$$FCCT[15-day]_{30mo+1.5e6} = 0.0857\ enr^2 - 1.3342\ enr + 12.856 \quad (5\text{-}33)$$

$$FCCT[30-day]_{18mo+1.5e6} = 0.0338\ enr^2 - 0.3502\ enr + 9.2596 \quad (5\text{-}34)$$

$$FCCT[30-day]_{24mo+1.5e6} = 0.0491\ enr^2 - 0.6582\ enr + 10.264 \quad (5\text{-}35)$$

$$FCCT[30-day]_{30mo+1.5e6} = 0.0812\ enr^2 - 1.251\ enr + 12.786 \quad (5\text{-}36)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 5.47-wt%, 6.92-wt% for the 24-month cycle, and 7.80-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5.25-wt%, 6.75-wt%, and 7.72-wt% for the 18, 24, and 30 month cycles. Increases in reload licensing costs result in very small increases in the enrichment at which the fuel cycle cost is minimum for all three cycles.

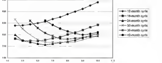

Figure 5-161 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with reload licensing costs decreased by 25%

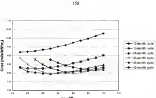

Figure 5-162. Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with reload licensing costs decreased by 25%

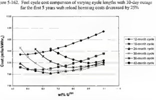

Figure 5-163 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with reload licensing costs decreased by 50%

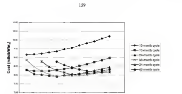

Figure 5-164 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with reload licensing costs decreased by 50%

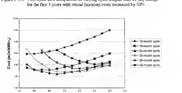

Figure 5-165 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with reload licensing costs increased by 25%

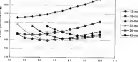

Figure 5-166 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with reload licensing costs increased by 25%

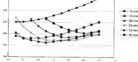

Figure 5-167 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with reload licensing costs increased by 50%

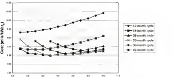

Figure 5-168. Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with reload licensing costs increased by 50%

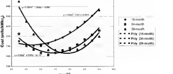

Figure 5-169. Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and reload licensing costs increased by 50%

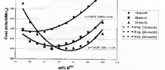

Figure 5-170 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and reload licensing costs increased by 50%

Effect of Variations in the Cost of Replacement Power

A base cost of $25\ \dfrac{mils}{kW\ \ hr_e}$ for replacement power was used in the model. As shown in Figures 5-19 through 5-57, the outage costs (which include \$20 million in labor) represents from 12 to 47% of the fuel cycle cost at their respective enrichment minimums. The percentage increases as the outage lengths increase and the cycle lengths decrease. The equations for the trendlines for a 100% increase in replacement power costs are presented in Equations 5-37 through 5-42

$$FCCT[15-day]_{18rp=50} = 0.0339\ \ enr^2 - 0.3682\ \ enr + 9.465 \quad (5\text{-}37)$$

$$FCCT[15-day]_{24rp=50} = 0.0519\ \ enr^2 - 0.7174\ \ enr + 10.62 \quad (5\text{-}38)$$

$$FCCT[15-day]_{30rp=50} = 0.0856\ \ enr^2 - 1.3342\ \ enr + 13.239 \quad (5\text{-}39)$$

$$FCCT[30-day]_{18cy=30} = 0.0336 \ enr^2 - 0.3509 \ enr + 10.586 \qquad (5\text{-}40)$$

$$FCCT[30-day]_{24cy=30} = 0.049 \ enr^2 - 0.6593 \ enr + 11.262 \qquad (5\text{-}41)$$

$$FCCT[30-day]_{36cy=30} = 0.0811 \ enr^2 - 1.2508 \ enr + 13.58 \qquad (5\text{-}42)$$

Differentiating the equations and setting them to zero yields the same enrichment minimums as the base economic model. Variations of the replacement power cost do not affect the enrichment at which specific cycle lengths have their minimum fuel cycle cost. Variations in the replacement power costs do, however, affect the cost savings or loss from switching to one cycle length to another. Using the base model values a reactor with an 18-month cycle using 5.0-wt% fuel and 15-day outage would lose $29,000 a year if it were to switch to a 24-month cycle. Reactors with a 30-day outage would save $1,543,000 if they switched from an 18-month to 24-month cycle. An increase of replacement power costs to 30 $\frac{mils}{kW \cdot hr_e}$ results in a gain of $271,000 (834.5%) saved per year for the 18-month cycle with 15-day outage by switching to a 24-month cycle. For 30-day outages, the cost savings is increased to $2,143,000 (38.9%) per year. If the replacement power cost is doubled to 50 $\frac{mils}{kW \cdot hr_e}$, the cost savings are increased to $1,471,000 (4,972.4%) and $4,543,000 (194.4%) a year for the 15-day and 30-day outage lengths. A reduction of replacement power costs to 20 $\frac{mils}{kW \cdot hr_e}$ would result in a loss of $329,000 (-1,234.5%) and a gain of $943,000 (-38.9%) a year. A further reduction to 15 $\frac{mils}{kW \cdot hr_e}$ yields a loss of $629,000 (-22,689.6%) a year for the 15-day outage and a reduced savings to $343,000 (-77.8%) a year for the 30-day outage. In general, for every

$5 \frac{mils}{kW \cdot hr_e}$ the replacement power cost is increased, the savings are increased by \$300,000 (1034.5%) per year for 15-day outage plants by going from an 18-month cycle to 24 months, and \$600,000 (38.9%) per year if the outage length is 30 days. The results from these calculations are presented in Figures 5-171 through 5-180 and in Tables E-54 through E-61 of Appendix E.

Effect of Variations in the Cost of Dry Cask Storage

A base charge of \$100 per kg for dry cask storage was used in the model. As shown in Figures 5-19 though 5-57, this typically represents only 2 or 3% of the fuel cycle cost at the respective fuel cycle minimums. A 10% increase in the cost of dry cask storage increases cost savings for the 18, 24, and 30-month cycles with 15-day outages to \$129,000 (41.2%), \$1,660,000 (4.0%), and \$5,185,000 (2.2%)a year if they switch from 5-wt% to their respective enrichment minimums. For the 30-day outage the cost savings

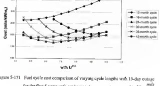

Figure 5-171 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with replacement power costs increased to 30 $\frac{mils}{kW \cdot hr_e}$

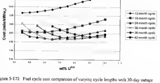

Figure 5-172 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with replacement power costs increased to 30 $\frac{mils}{kW \cdot hr_e}$

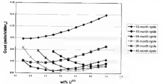

Figure 5-173 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with replacement power costs increased to 50 $\frac{mils}{kW \cdot hr_e}$

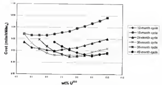

Figure 5-174 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with replacement power costs increased to 50 $\frac{mils}{kW \cdot hr_e}$

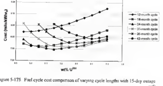

Figure 5-175 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with replacement power costs decreased to 20 $\frac{mils}{kW \cdot hr_e}$

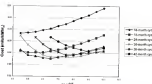

Figure 5-176 Fuel eycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with replacement power costs decreased to 20 $\frac{mils}{kW \cdot hr_e}$

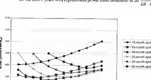

Figure 5-177 Fuel eycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with replacement power costs decreased to 15 $\frac{mils}{kW \cdot hr_e}$

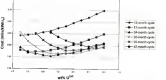

Figure 5-178 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with replacement power costs decreased to 15 $\frac{mils}{kW \quad hr_e}$

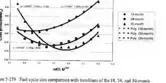

Figure 5-179 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and replacement power costs increased to 50 $\frac{mils}{kW \quad hr_e}$

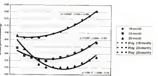

Figure 5-180 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and replacement power costs increased to $50\ \frac{mils}{kW\ hr_e}$

are increased to \$37,000 (193 6%), \$1,381,000 (4 7%), and \$4,654,000 (2 4%) with the enrichment minimum for the 18-month cycle increasing to 6 0-wt% An increase of 20% in dry cask storage costs increases cost savings to \$166,000 (82 4%), \$1,724,000 (8 1%), and \$5 299,000 (4 5%) per year for the 18, 24, and 30-month cycles with 15-day outages and \$73,000 (477 4%), \$1,443,000 (9 3%), and \$4,764,000 (4 8%) per year for 30-day outages. In general, for every 10% increase, the cost savings are increased by \$38,000 (41 2%), \$64,000 (4 0%), and \$113 000 (2.2%) per year for 18, 24, and 30-month cycles with 15-day outages For the 30-day outage plants the savings are increased by \$36,000 (193 6%) if 6 0 wt% instead of 5 5-wt% is chosen for the 18-month cycle, \$62,000 (4 7%) for the 24-month cycle, and \$109,000 (2 4%) per year for the 30-month cycle. Decreases of the same magnitude in dry cask storage costs would result in equal but opposite changes The results from these calculations are presented in Figures 5-181

through 5-190 and in Tables E-62 through E-71 of Appendix E.

A 2nd order polynomial trendline for the fuel cycle costs for the 18, 24, and 30-month cycles with a 50% increase in the cost of dry cask storage is presented in Figures 5-191 and 5-192. The equations for the trendlines for increased dry cask storage costs are given in Equations 5-43 through 5-48.

$$FCCT[15-day]_{18dev=150} = 0.0362\ enr^2 - 0.4133\ enr + 9.0503 \qquad (5\text{-}43)$$

$$FCCT[15-day]_{24dev=150} = 0.055\ enr^2 - 0.7769\ enr + 10.445 \qquad (5\text{-}44)$$

$$FCCT[15-day]_{30dev=150} = 0.0899\ enr^2 - 1.4157\ enr + 13.268 \qquad (5\text{-}45)$$

$$FCCT[30-day]_{18dev=150} = 0.0358\ enr^2 - 0.3938\ enr + 9.4747 \qquad (5\text{-}46)$$

$$FCCT[30-day]_{24dev=150} = 0.0519\ enr^2 - 0.7161\ enr + 10.559 \qquad (5\text{-}47)$$

$$FCCT[30-day]_{30dev=150} = 0.0852\ enr^2 - 1.3288\ enr + 13.181 \qquad (5\text{-}48)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 5.71-wt%, 7.06-wt% for the 24-month cycle, and 7.87-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5.50-wt%, 6.90-wt%, and 7.82-wt% for the 18, 24, and 30-month cycles. An increase in dry cask storage costs raises the enrichment at which the fuel cycle cost is minimum for all three cycles.

Effect of Variations in the Final Disposal Fee

A base fee of 1 $\dfrac{mil}{kW \cdot hr_e}$ was used in this model. This is a flat rate fee charged to utilities on the amount of electricity generated and sold from nuclear plants. This fee is used to finance a nuclear waste fund to provide for the permanent disposal of civilian

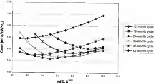

Figure 5-181 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with dry cask storage costs increased by 10%

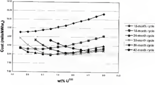

Figure 5-182 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with dry cask storage costs increased by 10%

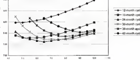

Figure 5-183 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with dry cask storage costs increased by 20%

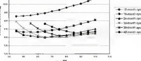

Figure 5-184 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with dry cask storage costs increased by 20%

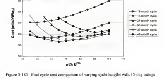

Figure 5-185 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with dry cask storage costs increased by 50%

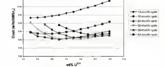

Figure 5-186 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with dry cask storage costs increased by 50%

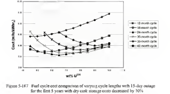

Figure 5-187 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with dry cask storage costs decreased by 10%

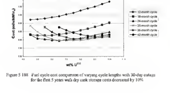

Figure 5-188 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with dry cask storage costs decreased by 10%

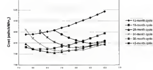

Figure 5-189 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with dry cask storage costs decreased by 20%

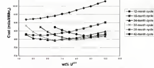

Figure 5-190 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with dry cask storage costs decreased by 20%

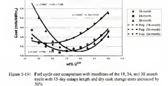

Figure 5-191 Fuel cycle cost comparison with trendlines of the 18, 24, and 30 month cycle with 15-day outage length and dry cask storage costs increased by 50%

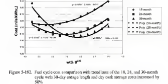

Figure 5-192. Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and dry cask storage costs increased by 50%

nuclear waste. Because it is a flat fee, increases or decreases to the fee have no effect on the enrichments at which individual fuel cycles have their minimums nor is there any incentive to use a smaller number of assemblies. In order to see the possible effects of a change in the way this fee is assessed, a simple calculation is done. The waste disposal fee is modified so that it is based on the number of batches used. The new fee, DF_2, is calculated as shown in Equation 5-49

$$DF_2 = 3\ \frac{BDF}{batches}\ (1 - \frac{OL}{C_M}) \qquad (5\text{-}49)$$

The only modification to the original disposal fee calculation is the multiplication by a factor of 3 and the division of the number of batches in the core. A 3 batch core would still be assessed a 1 $\frac{mil}{kW \cdot hr_e}$ disposal fee. Plants using more batches, and thus fewer assemblies, would be assessed smaller fees. A fee assessment policy such as this would encourage the use of fewer assemblies and in turn fewer spent fuel assemblies would have to be put into a permanent disposal site.

Under this revised fee assessment policy, 18-month cycle plants with a 15 day outage could save $2,128,000 by increasing their fuel enrichment to 6.5-wt%. The enrichment fuel cycle cost minimum for the 24-month cycle plants are increased to 8.0-wt% and moving to this enrichment would save $6,573,000 a year. The 30 month cycle would increase its enrichment minimum to 8.5-wt% and would save $14,257,000 a year. For the 30-day outage plants, the fuel cycle cost minimums occur at the same enrichments and would have cost savings of $1,727,000, $5,878,000, and $13,020,000 a year. The results of the calculations for this revised disposal fee assessment are presented in Figures 5-193 and 5-194 and in Tables E-72 through E-73 of Appendix E.

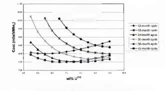

Figure 5-193 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with revised disposal fee assessment

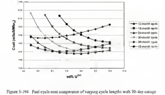

Figure 5-194 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with revised disposal fee assessment

Effect of Variations in the Fuel Purchase Interest Rate

A fuel purchase loan interest rate of 7% was used in the model. As shown in Figures 5-19 though 5-57, this interest rate causes the in core capital use charge to be 7 to 18% of the fuel cycle cost at the respective fuel cycle minimums. The percentages increase with longer cycle times and shorter outages. Fuel can be purchased at interest rates in the 5% to 6% range if short-term interest rates are used. Figures 5-195 through 5-198 compare the fuel cycle costs when the interest rate on fuel purchases is lowered to these rates. A decrease of the interest rates for fuel purchases from the base model of 7% to 6% increases cost savings for the 18, 24, and 30 month cycles with 15-day outages to $414,000 (353.6%), $2,063,000 (29.3%), and $5,967,000 (14.5%) a year if they switch from 5-wt% to their respective enrichment minimums, with the minimum for the 30-month cycle now at 8.5-wt%. For the 30-day outage the cost savings are increased to $317,000 (2,145.2%), $1,790,000 (35.7%), and $5,417,000 (16.4%) with the enrichment minimum for the 18-month cycle increasing to 6.0-wt% and the 30-month minimum enrichment increased to 8.0-wt%. A further decrease to an interest rate of 5% increases cost savings to $699,000 (666.7%), $2,476,000 (56.0%), and $6,452,000 (35.5%) per year for the 18, 24, and 30 month cycles with 15-day outages. The fuel cycle cost minimums occur at enrichments of 6.0 wt%, 7.0-wt%, and 8.5 wt%. If an outage length of 30 days is used the cost savings are $596,000 (4,629.3%), $2,206,000 (67.2%), and $6,197,000 (36.3%) if enrichments are increased to 6.0-wt%, 6.5-wt%, and 8.5-w% for the 18, 24, and 30-month cycles.

A 2[nd] order polynomial trendline for the fuel cycle costs for the 18, 24, and 30-month cycles with a decrease of fuel purchase interest rates to 5% is presented in Figures

5-199 and 5-200. The equations for the trendlines for the decreased fuel purchase interest rates are given in Equations 5-50 through 5-55.

$$FCCT[15-day]_{18M-5} = 0.0288\ enr^2 - 0.3803\ enr + 8.6414 \quad (5\text{-}50)$$

$$FCCT[15-day]_{24M-5} = 0.0468\ enr^2 - 0.7234\ enr + 9.9316 \quad (5\text{-}51)$$

$$FCCT[15-day]_{30M-5} = 0.0791\ enr^2 - 1.3148\ enr + 12.542 \quad (5\text{-}52)$$

$$FCCT[30-day]_{18M-5} = 0.0278\ enr^2 - 0.3553\ enr + 9.0584 \quad (5\text{-}53)$$

$$FCCT[30-day]_{24M-5} = 0.0438\ enr^2 - 0.6676\ enr + 10.074 \quad (5\text{-}54)$$

$$FCCT[30-day]_{30M-5} = 0.0746\ enr^2 - 1.2332\ enr + 12.482 \quad (5\text{-}55)$$

Differentiating the equations and setting them to zero yields a minimum for the 18-month cycle at 6.60-wt%, 7.73-wt% for the 24-month cycle, and 8.31-wt% for 30-month cycle plants with 15-day outages. For 30-day outage plants the minimums become 5.50-wt%, 6.90-wt%, and 7.82-wt% for the 18, 24, and 30-month cycles. Further calculations were done with fuel purchase interest rates set to 8, 9, 10, and 12% and are presented in Figures 5-201 through 5-218 and in Tables E-74 through E-85 of Appendix E. The minimums for trendlines at the varying interest rates are given in Table E-86. Decreases in the fuel purchase interest rate raises the enrichment at which the fuel cycle cost is minimum for all three cycles.

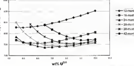

Figure 5-195 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate decreased to 6%

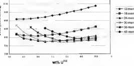

Figure 5-196 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate decreased to 6%

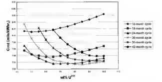

Figure 5-197 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate decreased to 5%

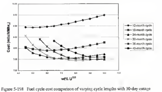

Figure 5-198 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate decreased to 5%

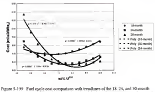

Figure 5-199 Fuel cycle cost comparison with trendlines of the 18 24, and 30-month cycle with 15-day outage length and fuel purchase interest rate decreased to 5%

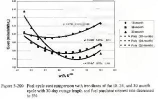

Figure 5-200 Fuel cycle cost comparison with trendlines of the 18 24, and 30 month cycle with 30-day outage length and fuel purchase interest rate decreased to 5%

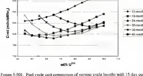

Figure 5-201 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate increased to 8%

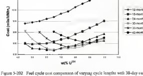

Figure 5-202 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate increased to 8%

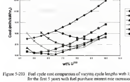

Figure 5-203 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate increased to 9%

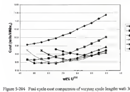

Figure 5-204 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate increased to 9%

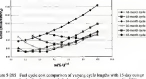

Figure 5-205 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate increased to 10%

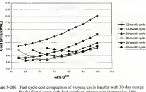

Figure 5-206 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate increased to 10%

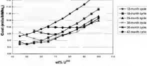

Figure 5-207 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fuel purchase interest rate increased to 12%

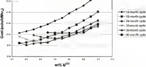

Figure 5-208 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fuel purchase interest rate increased to 12%

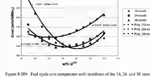

Figure 5-209 Fuel cycle cost comparison with trendlines of the 18, 24 and 30 month cycle with 15-day outage length and fuel purchase interest rate decreased to 6%

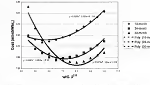

Figure 5-210 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fuel purchase interest rate decreased to 6%

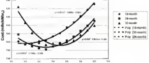

Figure 5-211 Fuel cycle cost comparison with trendlines of the 18, 24 and 30-month cycle with 15-day outage length and fuel purchase interest rate increased to 8%

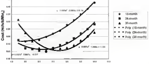

Figure 5-212 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fuel purchase interest rate increased to 8%

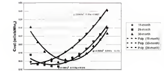

Figure 5-213 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and fuel purchase interest rate increased to 9%

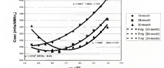

Figure 5-214 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fuel purchase interest rate increased to 9%

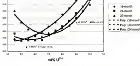

Figure 5-215 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and fuel purchase interest rate increased to 10%

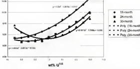

Figure 5-216 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fuel purchase interest rate increased to 10%

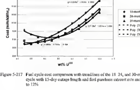

Figure 5-217 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 15-day outage length and fuel purchase interest rate increased to 12%

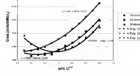

Figure 5-218 Fuel cycle cost comparison with trendlines of the 18, 24, and 30-month cycle with 30-day outage length and fuel purchase interest rate increased to 12%

CHAPTER 6
CONCLUSIONS

Research indicates that increasing enrichments to 10.0-wt% U^{235} is a viable option for most of today's equipment. The economic model indicates that there is little incentive for plants using an 18-month cycle to increase enrichment. For the base case models, the 24-month cycle is the most competitive. Up to 6.5-wt% is an attractive option economically for the 24-month cycle with interest rates up to 9.5%. It is suggested that a minimum of two reactors on a 24-month cycle participate in any program to increase enrichments in order for there to be an economic incentive to do so. A single reactor developing a 30-month cycle could see significant savings in such a program. Longer fuel cycles could only be achieved with enrichments greater than the currently licensed 5.0-wt% limit. These longer cycles would still have fuel cycle cost minimums in the range of 8.0 to 9.0-wt%, and, therefore, it is concluded that licensing and equipment modification beyond this point would be unnecessary for current PWR's in the United States.

Increasing ore costs lower the enrichment at which the fuel cycle has its minimum fuel cycle cost. Even with a 100% increase in ore cost there are still significant savings in going from the 5.0-wt% to higher enrichments for the 24 and 30-month cycles. Increasing conversion costs will also lower the enrichments for the fuel cycle cost minimums but since conversion is typically only one to three percent of the total fuel cycles costs its effect on the enrichment minimums and cost savings is relatively minor.

In comparison, changes to the SWU costs have a much greater impact on fuel cycle enrichment minimums and potential cost savings. Figure 6-1 shows a sensitivity study for a typical fuel cycle using increased enrichment. In this case the enrichment is the largest component and has the greatest effect on the overall fuel cycle cost. As shown in Figures 6-2 and 6-3, a 100% increase in SWU price would all but eliminate incentive for going to higher enrichments. Although the 24-month cycle would still see some savings, the 18-month cycle becomes the cheapest fuel cycle length and has minimums at 5-wt% or less. Figures 6-4 and 6-5 show a 50% decrease in SWU costs. In this case, not only is there incentive to increase enrichments, the longer fuel cycles become competitive.

Increases in fabrication cost also raise the cost savings from increased enrichment. Figures 6-6 and 6-7 compare the fuel cycle costs when the fabrication charges are increased by 100%. For the 15-day outage the 24 month cycle remains the most competitive but the 30-day outage has a minimum fuel cycle cost using the 30-month cycle at an enrichment of 8.0-wt%. There is only a 9% difference between the cost savings of a 24-month cycle going from 5.0 wt% to 6.5 wt% and the same plant going to the longer 30-month cycle with 8.0-wt% fuel. Increases of dry cask storage costs have a similar effect but to a lesser degree. Figures 6-8 and 6-9 compare the fuel cycle costs when the cost of dry cask storage is increased by 100%. In this case the 24-month cycle is the most cost effective for both outage lengths, but the 30-month cycle is a very close second at 8.0-wt% fuel for the 30-day outage case.

Reload licensing variations have little effect on cost savings for going to higher enrichments. Figures 6-10 and 6-11 compare the fuel cycle costs when the reload licensing costs are increased by 100%. There is little effect seen on the shape of the fuel

cycle cost curves, what is changed is the vertical position of the cycle-lengths. As reload licensing costs are increased, the longer cycles become more competitive. Variations of replacement power costs have a similar effect. An increase in replacement power cost also increases the potential cost savings of going to longer cycle lengths. Variations in the disposal fee have no effect on cost savings of increasing enrichments or cycle lengths. Modification to the way this fee is assessed in order to encourage the use of fewer assemblies could potentially encourage the use of higher enrichments by increasing the cost savings by millions per year.

Fuel purchase interest rates are the dominant factor in determining the cost savings or loss in using higher than 5.0-wt% fuel. At fuel purchase interest rates of 6 to 7% the economic model shows a potential savings of over 2 million dollars per year for reactors using a 24-month cycle and a savings of 5 to 6 million dollars per year if reactors were to develop a 30-month cycle. Increases in interest rates could result in very large losses if reactors were to go to higher enrichments. As long as the participating reactors did not contract to use the higher enrichments but only to pay for the licensing and equipment upgrades for the ability to go to higher enrichments they could minimize any potential losses. If a program is developed with 10 participating reactors, even if interest rates on purchase of fuel were raised to 20%, reactors on a 24-month cycle could go back to using 5-wt% fuel and only experience an investment loss of approximately $100 000 each year for a maximum of 5 years. Any time after that 5 year period, if the interest rates dropped and the utility purchased 6.5-wt% fuel at 7% interest then each plant could potentially save 1.4 to 1.7 million dollars a year, depending on the outage length. Fuel purchases at an interest rate of 9% would recoup the 5-year loss in less than a year.

While rising interest rates may deter participating plants from using higher enrichments, there is a potential savings of millions of dollars per year. Figures 6-12 and 6-13 display the monthly average Federal Funds interest rate over the last 20 years and the yearly average over the last 50 years [30]. The interest rate is currently at 1% but has been as high as 11.64% in the last 20 years and 19.10% (June, 1981) in the last 25 years. The model indicates that in order to see a savings from increased enrichments in the first five years the interest rate on purchases of fuel must be in the range of 9.5% or less. Although interest rates are volatile the potential gain appears to outweigh any loss that could be seen by increased enrichments beyond the current licensing limit of 5 wt% U^{235}.

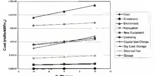

Figure 6-1. Sensitivity study of fuel cycle components to change for typical futuristic fuel cycle (24-month, 6.5-wt%, 15-day outage)

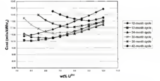

Figure 6-2 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost increased by 100%

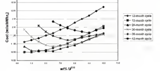

Figure 6-3 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost increased by 100%

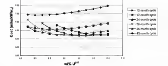

Figure 6-4 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with SWU cost decreased by 50%

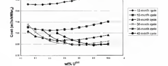

Figure 6-5 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with SWU cost decreased by 50%

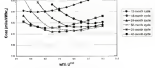

Figure 6-6 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with fabrication costs increased by 100%

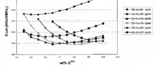

Figure 6-7 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with fabrication costs increased by 100%

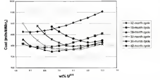

Figure 6-8 Fuel cycle cost comparison of varying cycle lengths with 15 day outage for the first 5 years with the cost of dry cask storage increased by 100%

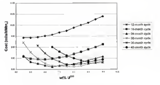

Figure 6-9 Fuel cycle cost comparison of varying cycle lengths with 30-day outage for the first 5 years with the cost of dry cask storage increased by 100%

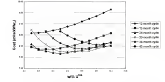

Figure 6-10 Fuel cycle cost comparison of varying cycle lengths with 15-day outage for the first 5 years with reload licensing costs increased by 100%

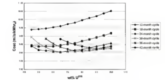

Figure 6-11 Fuel cycle cost comparison of varying cycle lengths with 30 day outage for the first 5 years with reload licensing costs increased by 100%

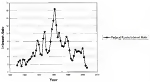

Figure 6-12. Historical Federal Funds interest rate over the last 50 years

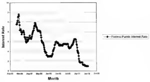

Figure 6-13 Historical Federal Funds interest rate over the last 20 years

APPENDIX A
MCNP INPUT FILES

This appendix contains all of the base case MCNP input files used to determine criticality limitations for equipment and facilities used in the manufacture, shipping and storage of nuclear fuel

The MCNP Input File Single 30B Container Completely Filled With 2-Foot Reflector

```
        UF6 in closed hessel with 20 inch reflecto worst case
1  1   -4.59331  -1  2 3          $ UF6
2  2   -8.210    1  3  -2 3       $ stainless steel drum
3  2   -8.210    2 -3 -3          $ stainless steel top
4  2   -8.210   -3 8 -8           $ stainless steel bottom
5  3   -1.99821  3  7  3 3        $ 23 inch water reflector
6  3   -1.99821  3 -8 -7          $ 23 inch water top
7  3   -9.99821 -8 8 -7           $ 20 inch water bottom
99 0    7 8 -9                    $ void outside of water reflector

1   cz   38.1     $ radius of UF6  inner rd of SS drum (30 in dia)
4   cz   33.37    $ outer radius of SS drum (1/2 inch thick)
7   cz   100.33   $ radius of water reflector (2 feet of water)
2   pz   90.32    $ top of inner drum  (73 inch height)
3   pz   36.52    $ bottom of inner drum
3   pz   97.79    $ top of outer drum
8   pz  -97.79    $ bottom of outer drum
8   pz   158.75   $ top of water reflector
9   pz  -158.73   $ bottom of water reflector

mode    n
imp:n    1 1 1 1 1 1 1 0
kcode    4000 1 10 230
ksrc     0 0 0
m1    92233  3.2336e-3  $ 3 wt%
      92233  3.2338e-3
      92238  0.9332e-3
       3019  5.1363e-2  $ F
       1001  7.3273e-3  $ H from HF
m2    26032  1.7021e-2
      26000  0.5027e-3
      26036  3.1806e-2
      23033  1.7793e-3
      10000  1.5092e-3
       3000  2.2390e 0
      13931  3.3833e-3
      13070  3.0838e-5
m3     8016  3.3368e-2  $ Water at 20 C
       1001  3.3736e-2
mt3  lwtr.01t
totnu
```

The MCNP Input File Single 30B Container, Filled to Licensed Limit, No Moderator, Lying on a Concrete Slab

```
          single 30B container  774 on side  concrete  air reflect  full
1  1    4.98281   -1 -9  $ UF6-HF mix (bottom)
2  2    8.310      1 -2  $ stainless steel drum
3  4    0.001293   2 -3  $ air around drum
4  3    2.237     -8     $ concrete
5  0   -1 9              $ void in barrel
99 0    3 4    $ void

1    RCC    0 96.52 39.37 0  193 04 0 34 10    $ inner barrel
2    RCC    0 97.79 39.37 0 -198 98 0 39.37    $ outter barrel
3    RPP   -109 33 109.33  158.75 198.75 0 0  139.70  $ air around drum
4    RPP    100 33 100.33  198.79 198.79  30 40 0 0  $ concrete floor
9    gz  80.512    $ plane cutting barrel for partially filled barrels

mode    n
imp:n   1 1 1 1 1 0
kcode   4000 1 10 240
ksrc    0 0 20
m1   92235  8.2986e-8  $ 5 wt%
     92234  3.2340e-4
     92238  8.5939e-3
      9019  5.1964e-2  $ F
      1001  7.4679e-4  $ H from HF
m2   24093  1.7031e-3  $ stainless steel
     26000  8.5827e-3
     24094  6.1084e-3
     25099  1.7059e-3
     18000  1.5892e-3
      6000  3.4498e-4
     19031  4.2090e-9
     15000  3.8938e-5
m3    1001  7.7469e-3  $ H in concrete
      8014  4.1930e-3  $ O
     11023  9.9530e-8  $ Na
     12000  1.4046e-4  $ Mg
     13027  2.3749e-3  $ Al
     14000  1.5116e-2  $ Si
     14033  9.4340e-9  $ S
     19000  4.6239e-4  $ K
     20000  2.7888e-3  $ Ca
     26000  3.0194e-4  $ Fe
m4    7014  4.1803e-9  $ N air around barrel
      8016  1.1201e-5  $ O
     18000  3.9099e-7  $ Ar
totnu
print
```

The MCNP Input File Single 30B Container, Completely Filled, No Moderator, Lying on a Concrete Slab

```
        single 30B container  UF6 on slab  concrete  air reflect, full
1  1   5 98381   1 -5 8 $ UF6-HF mix (bottom)
2  2  -8 317     1 -2 $ stainless steel drum
3  4   0 001293  3  3 $ air around drum
5  3   2 337    -5    $ concrete
9  1  -8 98381  -1 5  8 UF6-HF mix (top)
99 0   3 5   8 void

1   RCC   0 56.52 35 37 0 -103 08 0 38.10   $ inner barrel
2   RCC   0 97 79 35 37 0 -195 58 0 35 37   $ outter barrel
3   RPP   -100 33 100 33 -150 75 150 75 0 0 139 70  $ air around drum
8   RPP    100 33 100 33 -150 75 190 79 -30 48 0.0  $ concrete floor
9   pz  50 912   $ plane cutting barrel for partially filled barrels

mode    n
imp:n   1 1 1 1 1 0
kcode   5000 1 10 250
ksrc    0 0 20
m1   92235  5 3056e-4  $ 5 wt%
     92235  3 2358e-6
     92238  8 0935e 3
      9015  5 1665e-3 $ F
      1001  7 8679e-5 $ H from HF
m2   26052  1 7001e 3 $ stainless steel
     26068  8 5927e-9
     26058  6 1086e-2
     29095  1 7059e 3
     15007  1 5552e-3
      6000  2 8698e-6
     15031  0 7050e 5
     16000  2 0028e-5
m3    1001  7 7659e-3 $ H in concrete
      8018  5 1930e 3 $ O
     11023  5 5526e 5 $ Na
     12000  1 8086e-5 $ Mg
     13027  2 2765e 3 $ Al
     15007  1 5116e-3 $ Si
     15032  5 6280e 5 $ S
     19000  6 6229e 5 $ K
     30000  3 7550e-3 $ Ca
     25000  3 0194e-5 $ Fe
m4    7015  5 1582e 5 $ N air around barrel
      8016  1 1280e-5 $ O
     18000  2 5055e-7 $ Ar
totnu
print
```

The MCNP Input File Single 30B Container, Completely Filled, Water at 20 °C Moderator, Lying on a Concrete Slab

```
         single 30B container  UF6 on side  concrete  water reflect  full
1  1   8.58261   -1 -8  $ UF6-HF mix (bottom)
2  2   8.018      1 -2  $ stainless steel drum
3  4   0.10281    2 -3  $ water around drum
4  3   2.237      4     $ concrete
5  1   4.58261   -1  5  $ UF6-HF mix (top)
99 0   3 8   $ void

1   RCC   0 65 52 28 37 0 -182.78 0 28 10   $ inner barrel
2   RCC   0 97 79 38 37 0 -195 58 0 38 37   $ outer barrel
3   RPP    -100.22 100.22  -150.75 150.75  0.0 120.70  $ water around drum
4   RPP   -100.23 100.23 -150.75 150.75 -20.40 0.0  $ concrete floor
8   pz  47.512   $ plane cutting barrel for partially filled barrels

mode    n
imp:n   1 1 1 1 1 0
kcode   4000 1 10 200
ksrc    0 0 28
m1   92235  4.2540e-4  $ 5 wt%
     92234  2.2280e-5
     92238  8.0838e-3
      9019  5.1864e-2 $ F
      1001  7.4875e-4 $ H from HF
m2   24052  1.7021e-2 $ stainless steel
     26056  5.5327e-2
     26054  6.1086e-2
     28058  1.7995e-3
     14000  1.5472e-2
      6000  2.4038e-4
     15031  8.3881e-8
     16000  2.0828e-5
m3    1001  7.7868e-2 $ H in concrete
      8016  4.1936e-2 $ O
     11023  9.9638e-4 $ Na
     12000  1.4866e-4 $ Mg
     13027  2.2780e-3 $ Al
     14000  1.5116e-2 $ Si
     16032  5.6240e-5 $ S
     19000  8.6225e-8 $ K
     20000  2.7540e-3 $ Ca
     26000  3.0194e-4 $ Fe
m4    8016  2.3260e-2 $ Water at 20 C
      1001  6.6720e-2
mt4  lwtr.01t
totnu
print
```

The MCNP Input File 30B Containers in a Triangular Pitch, Completely filled, No Moderator, Lying on a Concrete Slab

```
        triangular pitch 30B containers  water  concrete base
c  barrel 1
1  1  -4 98361  -1      $ UF6-HF mix
2  2  -8 310     1  -2 $ stainless steel drum
c
c  barrel 2
3  1  -4 98361   3      $ UF6-HF mix
4  2  -8 310     3 -4  $ stainless steel drum
c
c  barrel 3
5  1  -4 98361  -5      $ UF6 HF mix
6  2  -8 310     5 -6  $ stainless steel drum
c
c  barrel 4
7  1  -4 98361  -7  17  $ UF6 HF mix
8  2  -8 310     7 -8 17 $ stainless steel drum
c
c  barrel 5
9  1  -4 98361   9      $ UF6-HF mix
10  2  -8 310    9 -17 $ stainless steel drum
c
c  barrel 6
11  1  -4 98361  -11      $ UF6-HF mix
12  2  -8 310    11 -12 $ stainless steel drum
c
c  barrel 7
13   1  -4 98361  -13     -18 $ UF6 HF mix
14  2   8 310      13  14 -18 $ stainless steel drum
c
15  4  -0 001233  2 4 6 8 10 12 14 -15 16 17  18 19  21 $ air around drums
16  3  -2 337   -15 16 17 -18 -19 20               $ concrete
99 0             15:-16:-17:18:-20:21               $ void

c   barrels
1   RCC   -1.27    78 76 30 37   103 04 0 0 38 10   $ inner barrel 1
2   RCC    0.00    78 76 30 37  -103 30 0 0 38 37  $ outer barrel 1
3   RCC   -1 37     0 00 39 37  -103 06 0 0 38 10   $ inner barrel 2
4   RCC    0 00     0 00 38 37   103 58 0 0 39 37   $ outer barrel 2
5   RCC    1.27    78 76 30 37  -103 06 0 0 38 10   $ inner barrel 3
6   RCC    0 00    78 74 39 37  -105 58 0 0 39 37   $ outer barrel 3
7   RCC   -1 27  -118 11 107 361   103 06 0 0 38 10 $ inner barrel 4 (1/3)
8   RCC    0 00  -118 11 107 301  -103 38 0 0 38 37 $ outer barrel 4 (1/3)
9   RCC   -1.27   -39 37 107 301   103 06 0 0 38 10 $ inner barrel 5
10  RCC    0 00    38 37 107 301   103 38 0 0 38 37 $ outer barrel 5
11  RCC   -1 37    38 37 107 301  -103 04 0 0 38 10 $ inner barrel 6
12  RCC    0 00    38 37 107 361   103 38 0 0 38 37 $ outer barrel 6
13  RCC    1.27   118 11 107 301  -103 06 0 0 38 10 $ inner barrel 7 (1/3)
14  RCC    0 00   118 11 107 301   105 58 0 0 38 37 $ outer barrel 7 (1/3)
c   model limits and concrete floor
15  px  30 480  $ front of model
16  px -226 06  $ back of model
*17  py  118 11  $ left of model
*18  py  118 11  $ right of model
19  pz   0 00  $ top of concrete floor
20  pz   30 60  $ bottom of floor and model
21  pz  177 611 $ top of model

mode    n
imp n   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
kcode   6000 1 15 360
ksrc    -97 0 7 30 0
m1   92235  4 3346e-4  $ 3 wt%
     92238  3 2360e-0
     92238  8 7535e-3
      9019  3 1664e 3 $ F
      1001  7 6670e-4 $ H from HF
```

```
m2   24052  1.2031e-3 $ stainless steel
     26056  8.5927e-3
     28058  0.1088e-3
     25055  1.7088e-3
     14028  1.54524-3
      6000  2.4668e-4
     15031  8.3050e-5
     16032  3.3030e-5
m3    1001  7.7689e-3 $ H in concrete
      8016  4.1030e-2 $ O
     11023  9.8530e-4 $ Na
     12000  1.4077e-4 $ Mg
     13027  2.2785e-3 $ Al
     14000  1.5116e-2 $ Si
     16032  5.6340e-5 $ S
     19000  4.8229e-8 $ K
     20000  1.7048e-3 $ Ca
     26000  3.0184e-4 $ Fe
m4    7014  4.1532e-5 $ N air around barrel
      8016  1.1288e-5 $ O
     18000  2.5089e-7 $ Ar
totnu
print
```

The MCNP Input File 30B Containers in a Triangular Pitch, Completely filled, Water at 20 °C Moderator, Lying on a Concrete Slab

```
      triangular pitch 30B containers; water  concrete base
c  barrel 1
1  1  -4.98301   1      $ UF6 HF mix
2  3  -8.310     1 -3 $ stainless steel drum
c
c  barrel 2
3  1  -4.98301  -3      $ UF6-HF mix
4  3  -8.310     3  4 $ stainless steel drum
c
c  barrel 3
5  1  -4.98301  -5      $ UF6-HF mix
6  3  -8.310     5 -6 $ stainless steel drum
c
c  barrel 4
7  1  -4.98301   7  17  $ UF6-HF mix
8  3  -8.310     7 -8 17 $ stainless steel drum
c
c  barrel 5
9  1  -4.98301  -9       $ UF6-HF mix
10  2  -8.310    9 -10 $ stainless steel drum
c
c  barrel 6
11  1  -4.98301   11      $ UF6-HF mix
12  3  -8.310    11 -12 $ stainless steel drum
c
c  barrel 7
13   1  -4.98301  -13      -19 $ UF6-HF mix
14  2  -8.310     13 -14  -19 $ stainless steel drum
c
15  4  -0.99281  2 4 6 8 10 12 14 -15 16 17 -18 19  21 $ water around drums
16  3  -2.237    -15 16 17  18  13 20                 $ concrete
99 0             13 -14 -17 18 -20 21                 $ void

c   barrels
1    RCC   -1.37   -70.74 30.37 -193.08 0 0 30.10   $ inner barrel 1
2    RCC    0.00   -70.74 30.37  133.30 0 0 33.37   $ outer barrel 1
3    RCC    1.37     0.00 30.37 -133.04 0 0 30.10   $ inner barrel 2
4    RCC    0.00     0.00 33.37 -195.50 0 0 39.37   $ outer barrel 2
5    RCC   -1.27    70.78 30.37  133.04 0 0 30.10   $ inner barrel 3
6    RCC    0.00    70.74 30.37 -193.30 0 0 39.37   $ outer barrel 3
7    RCC   -1.27  -110.11 107.381 -153.08 0 0 30.10 $ inner barrel 4 (1/2)
8    RCC    0.00   110.11 107.341  103.30 0 0 33.37 $ outer barrel 4 (1/2)
9    RCC   -1.37   -35.37 107.341 -103.04 0 0 30.10 $ inner barrel 5
10   RCC    0.00   -35.37 107.341  133.58 0 0 33.37 $ outer barrel 5
11   RCC    1.37    35.37 107.341 -133.04 0 0 30.10 $ inner barrel 6
12   RCC    0.00    35.37 107.341 -105.38 0 0 30.37 $ outer barrel 6
13   RCC   -1.37   110.11 107.341 -103.04 0 0 30.10 $ inner barrel 7 (1/3)
14   RCC    0.00   110.11 107.341 -103.30 0 0 30.37 $ outer barrel 7 (1/3)
c   model limits and concrete floor
15  px  30.400  $ front of model
16  px -224.04  $ back of model
*17  py -110.11  $ left of model
*18  py  110.11  $ right of model
19  pz    0.00  $ top of concrete floor
20  pz   30.40  $ bottom of floor and model
21  pz  177.411 $ top of model

mode   n
imp n  1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
kcode  8000 1 10 300
ksrc   -87 0 0 30 0
m1   92233  8.2980e-8  $ 5 wt%
     92234  3.2340e-4
     92238  8.7032e-3
      9019  5.1864e-2 $ F
      1001  7.4673e-4 $ H from HF
```

```
m2   24052  1.3021e-2 $ stainless steel
     26000  5.5827e-2
     28058  8.1088e-2
     25055  1.7099e-3
     14000  1.5492e-2
      6000  2.4000e-4
     15031  8.2850e-5
     16000  2.7820e-5
m3    1001  7.7069e-3 $ H in concrete
      8016  4.1020e-2 $ O
     11023  9.6530e-4 $ Na
     12000  1.4088e-4 $ Mg
     13027  2.2785e-3 $ Al
     14000  1.5110e-2 $ Si
     16032  8.8340e-5 $ S
     19000  8.4229e-4 $ K
     20000  2.7840e-3 $ Ca
     26000  2.7104e-4 $ Fe
m4    8016  3.3268e-2 $ Water at 20 C
      1001  6.6726e-2
mt4  lwtr.01t
totnu
print
```

The MCNP Input File Wet Processing of 5-wt% UO_2, 2.056 g U/cc, 6.065-inch diameter SS Pipe

```
Wet Processing of UO2 with 5 w/o U-235, 2.056 g U/cc  6.065 in ss pipe
1  1  -3.110 -1         $ slurry
2  2  8.210  1  4       $ stainless steel pipe
3  3  -1.000  4 -5      $ 12 inch water reflector
99 0  5                 $ void outside of water reflector

1   cz  7.703  $ radius of slurry  inner rd of SS pipe
4   cz  8.414  $ outer radius of SS pipe
5   cz  38.894 $ radius of water barrier

mode   n
imp:n   1 1 1 0
kcode  4000 1 10 810
ksrc   0 0 0
m1   92235.60c  3.0319e-4
     92238.60c  5.8374e-3
      8016.60c  1.2401e-2
      1001.60c  5.2650e-2
      8016.60c  2.8325e-2
m2   24052.60c  1.7021e-2
     26056.60c  5.5927e-3
     24050.60c  1.1806e-2
     25055.60c  1.7099e-3
     28058.60c  1.5402e-3
      6000.60c  2.4000e-4
     15031.60c  3.8558e-5
     16032.60c  2.8838e-5
m3    8016.60c  3.3428e-2
      1001.60c  6.6856e-2
mt3  lwtr.01t
totnu
print
```

The MCNP Input File Wet Processing of 7-wt% UO_2, 1.280 g U/cc, 7.981-inch diameter SS Pipe

```
        Wet Processing of UO2 with 7 w/o U-235, 1.280 g U/cc, 7.981 in SS pipe
1  1   -2.320 -1        $ slurry
2  2   -8.210  1 -4     $ stainless steel pipe
3  3   -1.000  4 -5     $ 12 inch water reflector
99 0    5               $ void outside of water reflector

1   cz  10.120  $ radius of slurry, inner rd of SS pipe
4   cz  10.950  $ outer radius of SS pipe
5   cz  41.434  $ radius of water barrier

mode    n
imp:n   1 1 1 0
kcode   4000 1 10 410
ksrc    0 0 0
m1   92235.60c  2.2861e-4
     92238.60c  3.0121e-3
      8016.60c  6.4826e-3
      1001.60c  5.5003e-2
      8016.60c  2.9002e-2
m2   26052.60c  1.7021e-2
     26160.60c  0.5027e-3
     26150.60c  6.1016e-2
     25055.60c  1.7690e-3
     16000.60c  1.5092e-3
      6000.60c  2.4670e-4
     15031.60c  6.2850e-5
     16000.60c  3.0030e-5
m3    8016.60c  2.3420e-2
      1001.60c  6.6856e-2
mt3  lwtr.01t
totnu
print
```

The MCNP Input File Wet Processing of 7-wt% UO_2, 0.80 g U/cc, 10.02-inch diameter SS Pipe

```
        Wet Processing of UO2 with 7 w/o U-235, 0.800 g U/cc, 10.02 in SS pipe
1  1  -1.825 -1        $ slurry
2  2  -8.210  1 -4     $ stainless steel pipe
3  3   1.000  4 -5     $ 12 inch water reflector
99 0   5               $ void outside of water reflector

1   cz  12.725  $ radius of slurry, inner rd of SS pipe
4   cz  13.653  $ outer radius of SS pipe
5   cz  46.133  $ radius of water barrier

mode    n
imp:n   1 1 1 0
kcode   5000 1 10 610
ksrc    0 0 0
m1    92235.60c  1.6361e-4
      92238.60c  1.0820e-3
       8016.60c  6.0521e-2
       1001.60c  6.1323e-2
       8018.60c  3.0462e-2
m2    24052.60c  1.7021e-2
      26000.60c  5.5927e-3
      26056.60c  6.1806e-2
      25056.60c  1.7469e-2
      14000.60c  1.6892e-3
       6000.60c  2.6060e-4
      16031.60c  6.2050e-5
      16000.60c  3.0820e-5
m3     8016.60c  3.2420e-2
       1001.60c  6.6858e-2
mt3   lwtr.01t
totnu
print
```

The MCNP Input File Dry Conversion Reactor Containing 5-wt% UO_2 and Moderated by Water at 20 °C

```
Dry conversion base case 3 wt%
1 1 -2 8175      1 -3 3 -4 3 6    $ 4 + water in lower section
2 3 -3 333    3 -7 8 3 -10 11    $ 6 + water in middle section
3 3 -8 44   #1 33 -12            $ inconel middle section
4 2  8 33   31 33  13            $ inconel lower section
5 4 -0 99821 31 33 33 33 -14     $ moderator
6 3  0 3303 31 #3 #3 33 #3 -13   $ insulator
99 0           13                $ void

1  pz    0.0  $ bottom of inside lower section
2  pz 144.12  $ top of inside lower section
3  py  33.18  $ left of inside lower section
4  py  35.18  $ right of inside lower section
5  px   3.715 $ front of inside lower section
6  px  -3.713 $ back of inside lower section
7  pz 320.03  $ top of middle section
8  py  33.33  $ left of inside middle section
9  py  49.33  $ right of inside middle section
10 px   3.323 $ front of inside middle section
11 px  -3.333 $ back of inside middle section
12 RPP -14.16 16 13 -30 133 30 133 144 12 320 03 $ middle inconel
13 RPP  -3 33 8 33 33 813 33 103 0 63 138.13     $ lower inconel
13 RPP -33 3 23 3 -37 935 37 333 -11 43 320 05  $ moderator
13 RPP  38.10 38 10 -40 633 40 643 -33 33 330 03 $ insulation

mode   n
impin  1 1 1 1 1 1 0
kcode  3000 1 10 300
ksrc   4 4 29
m1    33333  1 3337e 3
      33333  3 3303e-3  $ 3 wt%
      92238  3 2329e-3
       8016  3 3332e 3 $ O
       1001  3 4332e-3 $ 4
m2    92233  1 3937e-3
      33333  3 3582e 3  $ 3 wt%
      92238  3 3339e-3
       8016  1 3336e 3 $ O
       1001  1 3033e-3 $ 4
m3    28000  5 2700e-2  $ Inconel 623
      24000  3 3306e 3
      42000  3 2381e-3
      22000  3 3372e-5
       3012  3 3317e-3
      14000  3 0384e-3
      23000  1 3330e 3
      27039  0 3333e-4
      41033  1 7232e-3
      13027  7 3339e-3
m4     8013  3 3381e-2 $ water
       1001  6 3739e 3
mt3  lwtr 01t
m5     8013  3 16733e-3 $ insulation from H&H
      13027  2 33033e-3
      14000  1 30010e-5
totnu
print
```

The MCNP Input File Calciner Containing 5-wt% UO_2 and Moderated by Water at 20 °C

```
        calciner base case template
1  1  -2 8160   -1     $ U and water in calciner
2  2  7 87       1  2 $ calciner wall
3  3  -1e-6      2 -3 $ air above shroud
4  8  -2 222     2 -4 $ U in shroud
5  5  -8 1281   -5    $ heater (back)
6  5  8 1281    -6    $ heater (front)
7  6  8 8281     21 82 83 82 25 86 7 $ insulation
8  7  -8 22821        7 8 $ reflector region
99 0   0   $ void

1   RCC   0 -384 0 0 0 610 0 0 12 70    6 inner calciner
2   RCC   0 -382 0 0 0 610 0 0 15 87    6 outer calciner
3   RPP   -22 12 28 12 -202 0 302 0 0 0 28 15  $ air above shroud
4   RPP   -22 13 22 13  302 0 502 0  22 12 0.0 0 U in shroud
5   RPP   -21 72 -22 15  -202 0 203 0 -22 12 22 15 $ back heater
6   RPP    28 13  31 75  -312 0 314 0  28 13 22 15 $ front heater
7   RPP   -27 625 27 622 -221 98 221 86 -22 22 26 22 $ insulation
8   RPP   -77 622 77 622 -261 86 261 86 -76 22 76 52 $ reflector

mode    n
impin   1 1 1 1 1 1 1 1 1 0
kcode   2000 1 10 260
ksrc    0 0 0
m1    92238  1 6257e-0 $ U and water in calciner
      22222  2 2203e-2 $ 5 wt%
      22228  2 2289e-5
       8016  3 8201e 2 $ O
       1001  5 2222e-2 $ H
m2    26000  2 2787e-2 $ calciner wall
      28000  2 8221e 2
      26000  5 8252e-2
      25052  1 7253e 5
      12000  5 2729e 5
m3     8016  5 2827e-0 $ air in top half
       1001  6 3852e 0
mt2  lwtr 01t
m4    22228  1 6257e-6 $ U and water in shroud
      22252  2 2282e-4 $ 5 wt%
      92258  2 2222e-5
       8018  1 8326e 2 $ O
       1001  1 2822e-2
m5    12000  6 5879e-4 $ heater material at 20% TD
      13027  7 2122e-4
       8016  2 2217e-3
m6    12000  2 3122e 2 $ insulation material at 10% TD
      13027  5 5622e-2
       8018  1 8160e 5
m7     8010  5 3227e 2 $ reflector (water)
       1001  6 6735e-2
mt7  lwtr 01t
totnu
print
```

The MCNP Input File Single Molybdenum Pellet Boat Completely Packed with 5-wt% UO_2 Pellets and Moderated by Water at 20 °C

```
Single boat, slurry, tightly packed
1  1   10.0338  -1      5 UO2-water mix
2  2   -10.2         1  2 $ molybdenum boat
3  3   -0.99281    2 -3 $ moderator around boat
58 0   3                5 void

1   RPP    15.001 15.001 -10.954 10.954  0 79275 10.5838  $ UO2 water mix
2   RPP    15.557 15.557  11.43  11.43   0 0      10.9538  $ molybdenum
3   RPP   -46.037 46.037 -41.31  41.31 -30.48     41.4338  $ water

mode    n
imp:n   1 1 1 0
kcode   4000 1 10 200
ksrc    0 0 5
m1    92235  1.1223e-3  $ 5 wt% cent
      92234  0.4176e-6
      92238  2.1047e-2
       1001  6.3130e-3 $ 0
       8016  4.7961e-2 $ 0
m2    42000  8.4825e-2 $ molybdenum cent
m3     8016  3.3367e-2 $ Water at 20 C
       1001  6.6733e-2
mt3   lwtr.01t
totnu
print
```

The MCNP Input File Single Molybdenum Pellet Boat One-Third Packed with 5-wt% UO_2 Pellets and Moderated by Water at 20 °C

```
         Single boat  slurry
1  1     4 3183    -1       $ UO2 water mix
2  2     10 3       1 -2    $ molybdenum boat
3  3     0 33201    2  3    $ moderator around boat
99 0     3                  $ void

1    RPP     15 881 15 881  10 954 10 954   0 75375 17 5530   $ UO3 water mix
2    RPP    -15 957 15 957 -11 03  11 03   [illegible]   17 9530   $ molybdenum
3    RPP     48 037 48 037 -41 51  41 51   37 40      41 4330   $ water

mode    n
imp:n   1 1 1 0
kcode   4000 1 10 260
ksrc    0 0 5
m1    92235   4 1353e-4   $ 5 wt% feed
      92238   3 0539e-6
      92238   7 7238e-3
       1001   8 4496e-2 $ H
       8016   3 8548e 2 $ O
m2    42000   8 4035e-3 $ molybdenum feed
m3     8016   3 3367e-2 $ Water at 20 C
       1001   8 8733e 3
mt3   lwtr 01t
totnu
```
print

The MCNP Input File Infinite Array of Molybdenum Pellet Boats One-Third Packed with 5-wt% UO_2 Pellets on ¼ Inch Steel Shelf and Moderated by Water at 20 °C

```
      6 boats - reflected ends  shelf  1 ft water
1  0  -3            fill=1  imp:n=1 $ 1st boat
2  1  -4.3188  -1     u=1  imp:n=1 $ UO2 water mix
3  2  -10.2    1 -2  u=1  imp:n=1 $ molybdenum boat
4  like 1 but trcl=(0  22.83 0)  imp:n=1 $ 2nd boat
5  like 1 but trcl=(0  22.83 0)  imp:n=1 $ 3rd boat
6  like 1 but trcl=(0  45.72 0)  imp:n=1 $ 4th boat
7  like 1 but trcl=(0  45.72 0)  imp:n=1 $ 5th boat
8  like 1 but trcl=(0 -68.58 0)  imp:n=1 $ 6th boat
9  4  -8.21      3                imp:n=1 $ steel shelf
10 3  -0.998207   4 3 -7 8 -9 10  11          imp:n=1 $ water

1   RPP  -13.081 13.081 -11.334 11.334  0.73373 18.9338  $ UO2 water mix
2   RPP  -15.557 15.557 -11.43  11.43   0.0     18.9338  $ molybdenum
3   RPP  -13.557 13.337  11.43  11.43   0.0     18.9338  $
4   RPP  -15.337 13.337 -80.01  57.15   0.635   18.9338  $ boxes + shelf
5   RPP   13.337 13.337  80.01  57.15  -0.635   0.0      $ ss shelf
*5   px    -43.837
*7   px     46.837
*8   py    -80.011
*9   py     57.151
*10  pz     31.113
*11  pz     41.4338

mode    n
kcode   4000 1 10 200
ksrc    0 0 5
m1    92235  4.1232e-4  $ 5 wt% test
      92234  3.0331e-3
      92238  7.7350e-3
       1001  4.4430e-2 $ H
       8016  3.8348e-2 $ O
m2    42000  3.4025e-2 $ molybdenum test
m3     8016  3.3037e-2 $ 0.1 g/cc Water at 20 C
       1001  3.3733e-2
mt3   lwtr.01t
m4    24052  1.7021e-2 $ stainless steel
      26056  5.9427e-2
      28058  1.1884e-2
      25055  1.7639e-3
      14028  1.5492e-3
       6012  2.4630e-4
      16032  3.3839e-3
      15031  3.2838e-3
totnu
print
```

The MCNP Input File Single 17x17 Assembly with 5-wt% UO_2 Moderated by Water at 20 °C

```
   one 17x17 assembly  water at 20 C
c
c  fuel pin
1    1  -10.58   -1          u=1 imp:n=1 $ fuel
2    0            1  -2        u=1 imp:n=1 $ gap
3    2  -6.5      2 -3         u=1 imp:n=1 $ clad
4    5 -0.99821   3
        Vol=380 10           u=1 imp:n=1 $ moderator
c
5    5 -0.99821   20         u=2 imp:n=1 $ moderator
6    2 -6.5       20 -25     u=2 imp:n=1 $ clad
     5 -0.99821   25
       Vol=168 99            u=2 imp:n=1 $ moderator
10  5  -0.99821  4 5 -6 7 lat=1 u=3 imp:n=1 fill= 0 0 -8 8 0 0
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
            1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
            1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
            1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
11 0     -10 11  12 13 -8 9 fill=3 imp:n=1 $ 1st assembly
100 5 -0.99821  -8 9 (10:-11:12:-13)  15
                              imp:n=1 $ moderator around assemblies inside cask
101 5 -0.99821   8  15  18    imp:n=1 $ moderator above assemblies inside cask
102 5 -0.99821  -9 -18  20    imp:n=1 $ moderator below assemblies inside cask
103 0  15 imp:n=0 $ around system
104 0 -20 imp:n=0 $ below system
105 0  18 imp:n=0 $ above system

c  geometry cards
c
1  cz    0.4150   $ fuel pellet radius
2  cz    0.42037  $ M5 clad inner radius
3  cz    0.47244  $ M5 clad outer radius
4  py    0.63758  $ moderator
5  py   -0.63754
6  px    0.63758
7  px   -0.63754
8  pz    182.88   $ top of fuel
9  pz   -182.88   $ bottom of fuel
10 px   10.83018 $ assembly
11 px  -10.83018
12 py   10.83018
13 py  -10.83018
15 cz    50.374   $ moderator radius
18 pz   253.6855  $ inner top cask
20 pz  -253.6825  $ inner bottom cask
28 cz 0.5715      $ IGT
29 cz 0.61214     $ IGT

mode    n
kcode   4000 1 40 410
sdef  axs 0 0 1  ext d2  rad d1  pos 45
si1   0 0.4125
si2   -182 182
sp3   0.25 0.25 0.25 0.25
```

```
e13 1  5 10033   5 10033      0
       5 10032   5 10032      0
      -5 10032   5 10032      0
       5 10033  -5 10033      0
m1    92234 1 1138e-5 $ UO2 pellet
      92235 1 4850e-3 $ 6 07 wt% U-235 at 100k TG
      92238 3 3881e-3
       8016 8 8914e-3
m2    40000 4 3434e-3 $ M 5
      41093 8 2133e-4
       8016 3 1885e-8
m3    24000 1 7021e-3 $ steel
      28060 8 5827e-3
      26056 6 1086e-3
      25055 1 7008e-3
      14000 1 5483e 3
       6000 3 8880e-4
      15031 8 3050e 5
      16000 3 7030e 5
m4    24053 1 6585e 2 $ borated steel
      28060 8 3742e 3
      26058 5 9538e-3
      25055 1 8886e 3
      14000 1 5098e-3
       6000 3 4073e 4
      15031 6 3331e-5
      16000 3 0858e-5
       5010 1 4385e 3 $ 1 5 wt% boron
       5011 5 3391e-3
m5     1001 3 3388e 3 $ Water at 20 C
       1001 6 6736e-3
mt5  lwtr.01t
m6     6000 1 5543e 3 $ BPRA
       5010 1 1131e-3
       5011 4 0747e-3
       8016 5 3506e 3
      13027 3 5386e-2
totnu
print
```

The MCNP Input File Single 15x15 Assembly with 5-wt% UO_2 Moderated by Water at 20 °C

```
   single 15x15 assembly in water
c
c  fuel pin
1     1  -10.96    1            u=1 imp:n=1 $ fuel
2     0            1 -2         u=1 imp:n=1 $ gap
3     2  -6.5      2 -3         u=1 imp:n=1 $ clad
4     5  -0.99821  3
         Vol=442.68e            u=1 imp:n=1 $ moderator
c  tubes for BPRA s
5     5  -0.99821  -30          u=3 imp:n=1 $ water
6     2  -6.5       30 -31      u=3 imp:n=1 $ clad
10    5  -0.99821   31
         Vol=244.6202           u=2 imp:n=1 $ moderator
c
c  instrument guide tube
11    5  -0.99821   32          u=3 imp:n=1 $ moderator
12    2  -6.5       32 -33      u=3 imp:n=1 $ clad
13    5  -0.99821   33
         Vol=214.90              u=3 imp:n=1 $ moderator
14  5  -0.99821  4 5 -6 7 lat=1 u=4 imp:n=1 fill=-7:7 -7 7 0 0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 1 3 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 3 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 3 1 1 1 1 1 1 1 1 3 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0       10 11  12 13  8 9 fill=4 imp:n=1 $ 1st assembly
100 5 -0.99821  -8 9 (10:-11:12:-13) -16
                                 imp:n=1 $ moderator around assemblies inside cask
101 5 -0.99821   8  10 -20       imp:n=1 $ moderator above assemblies inside cask
102 5 -0.99821  -9 -10  22       imp:n=1 $ moderator below assemblies inside cask
108 0    10 imp:n=0 $ around system
109 0    23 imp:n=0 $ below system
110 0    24 imp:n=0 $ above system

c  geometry cards
c
1  cz    0.409594   $ fuel pellet radius
2  cz    0.46990   $ M5 clad inner radius
3  cz    0.535700  $ M5 clad outer radius
4  py    0.721360  $ moderator
5  py    0.721360
6  px    0.721360
7  px    0.721360
8  pz    182.88    $ top of fuel
9  pz    182.88    $ bottom of fuel
10 px    10.8204 $ assembly
11 px   -10.8204
12 py    10.8204
13 py   -10.8204
16 cz    50.574 $ inner cask radius
20 pz   282.0938    $ inner top cask
21 pz   254.00     $ outer top cask
22 pz    283.0035   $ inner bottom cask
23 pz   -254.00    $ outer bottom cask
30  pz 314.96       $ top water boundary
31  pz  314.96      $ bottom water boundary
30  cz 0.635       $ guide tube
```

```
[illegible] 0 67266   $
32  cz 0 662610  $ instrument guide tube
36  cz 0 666670  $
34  py 11 66666  $ steel shelf

mode    n
kcode   6000 1 60 610
sdef  axs 0 0 1  ext d0  rad d1  pos 86
si1   0.8166
si6   -186 186
sp1   0 26 0 26 0 25 0 26
si6 1   6 32016    6 32016      0
       -0 62016   -6 36016      0
        6 36016    6 36016      0
        6 66016   -6 26016      0
m1    92260 9.2017e-6 $ UO2 pellet
      92666 1.6676e-6 $ 6 00 wt% 0-635 at 1001 TD
      92260 6.3207e-6
       8016 6.26011 6
m2    80000 0.6066e-2 $ H-5
      61066 6.6132e-4
       8016 6.1016e-6
m3   66056  1.7061e-6 $ steel
     60000  0.6667e-6
     20056  6.2100e-2
     25066  1.7116e-6
     10000  1.5062e-6
      8000  2.6050e-6
     16061  6.6061e-6
     16000  6.0060e-6
m4   66066  1.6606e-6 $ borated steel
     60000  0.6760e-6
     26050  5.9530e-6
     66066  1.6666e-6
     10000  1.5090e-6
      8000  2.8176e-6
     16061  6.8661e-6
     16000  6.0056e-5
      6010  1.6606e-6 $ 1 6 wt% boron
      6011  6.6661e-6
m5    0016  6.6670e-2 $ Water at 20 C
      1001  6.6766e-6
mt6  lwtr 01t
m6    6000  1.6663e-6 $ SPRA
      6010  1.1131e-6
      5011  0.0747e-6
      8010  6.6606e-6
     13027  6.5206e-2
totnu
print
```

The MCNP Input File Single 15x15 Assembly with 5-wt% UO_2 and Steel Rod Inserts Moderated by Water at 20 °C

```
    single 15x15 assembly in water
c
c  fuel pin
1     1   10 30    1          u=1 imp:n=1 $ fuel
2     0            1 -2       u=1 imp:n=1 $ gap
3     2   8.3      2  2       u=1 imp:n=1 $ clad
4     5 -0.99821   3
          Vol=442.034         u=1 imp:n=1 $ moderator
c  tubes for SPNA 9
5     2   8.21     1          u=2 imp:n=1 $ steel rod
6     0            1 -2       u=2 imp:n=1 $ gap
7     2   8.21     2  2       u=2 imp:n=1 $ steel clad
8     5  -0.99821 3 -20       u=2 imp:n=1 $ water
9     2  -6.5        30  21   u=2 imp:n=1 $ clad
10    5  -0.99821   31
          Vol=284.0282        u=2 imp:n=1 $ moderator
c
c  instrument guide tube
11    5   0.99821    22       u=2 imp:n=1 $ moderator
12    2  -6.5       32 -22    u=2 imp:n=1 $ clad
13    5   0.99821    22
          Vol=214.50            u=3 imp:n=1 $ moderator
14  5    0.99821  4 5  6 7 lat=1 u=4 imp:n=1 fill=-7:7 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0     -10 11 -12 13 -8 9 fill=4 imp:n=1 $ 1st assembly
100 5  0.99821    8 9 (10 -11 12 -12) -18
                                imp:n=1 $ moderator around assemblies inside cask
101 5  0.99821    8  10  20     imp:n=1 $ moderator above assemblies inside cask
102 5  0.99821   -9 -10  22     imp:n=1 $ moderator below assemblies inside cask
108 0     18 imp:n=0 $ around system
109 0     23 imp:n=0 $ below system
110 0     20 imp:n=0 $ above system

c  geometry cards
c
1  cz   0.839088   $ fuel pellet radius
2  cz   0.48050   $ HS clad inner radius
2  cz   0.525700  $ HS clad outer radius
8  py   0.721240  $ moderator
9  py  -0.721280
6  px   0.721360
7  px   0.721280
8  pz   182.88    $ top of fuel
9  pz   102.88    $ bottom of fuel
10 px   10.8210 $ assembly
11 px   10.8214
12 py   10.8214
12 py  -10.8214
18 cz   90.378 $ inner cask radius
20 pz   253.9825    $ inner top cask
21 pz   254.00     $ outer top cask
22 pz  -252.8825  $ inner bottom cask
22 pz   254.99     $ outer bottom cask
```

```
28  pz 316.56      $ top water boundary
29  pz -315.55     $ bottom water boundary
50  cz 0.555       $ guide tube
51  cz 0.57055     $
52  cz 0.562810    $ instrument guide tube
53  cz 0.555578    $
54  py 11.29505    $ steel shelf

mode    n
kcode   5000 1 00 510
sdef  axs 0 0 1  ext d3  rad d1  pos d5
si1    0.5155
si2    -182 182
sp1    0.55 0.25 0.25 0.25
si3 l   5.55010   5.35010     0
       -5.52015  -5.55016     0
        5.55016   5.55010     0
        5.52015  -5.52010     0
m1     95534 5.2417e-8 $ UO2 pellet
       92235 1.5576e-5 $ 5.00 wt% U 235 at 100% TD
       92238 5.3207e-5
        8016 5.0008e-5
m2     40000 4.5554e-5 $ Zr-5
       51055 5.5155e-5
        8016 5.1005e-5
m3   25055   1.7801e-2 $ steel
     28000   8.5927e-5
     25055   5.1065e-2
     55055   1.7655e-5
     14000   1.5555e-5
      6000   5.5530e-5
     15031   0.5850e-5
     16000   5.7830e-5
m5   55055   1.5585e-5 $ borated steel
     58060   8.5755e-5
     26050   5.9538e-2
     25055   1.5555e-5
     14000   1.5090e-5
      6000   2.5075e-5
     15031   5.5551e-5
     15000   3.0036e-5
      5010   1.5505e-5 $ 1.5 wt% boron
      5011   5.3591e-5
m5    8016   5.5388e-2 $ water at 20 C
      1001   8.8736e-5
mt5  lwtr.01t
m6    5000   1.5555e-5 $ BPRA
      5010   5.1151e-5
      5011   5.0757e-3
      8016   5.5506e-2
     13027   5.5286e-2
totnu
print
```

The MCNP Input File Single 15x15 Assembly with 5-wt% UO_2 and BPRA Moderated by Water at 20 °C

```
   single 15x15 assembly in water
c
c  fuel pin
1    1 -10.56    1          u=1 imp:n=1 $ fuel
2    0           1 -2        u=1 imp:n=1 $ gap
3    3 -6.5      2 -3        u=1 imp:n=1 $ clad
4    5 -0.95831  3
       Vol=441.654           u=1 imp n=1 $ moderator
c  tubes for BPRA s
5    6 -3.1    -1            u=3 imp:n=1 $ burnable poison
6    0          1 -3         u=3 imp n=1 $ gap
7    3 -8.31    3 -3         u=2 imp n=1 $ steel clad
8    5 -0.95831 3  30        u=3 imp n=1 $ water
9    2 -6.5        30 -31    u=2 imp:n=1 $ clad
10   5  0.95821   31
       Vol=344.6203          u=3 imp n=1 $ moderator
c
c  instrument guide tube
11   5 -0.95821  -32         u=3 imp n=1 $ moderator
12   3 -6.5       30 -33     u=3 imp n=1 $ clad
13   5 -0.95831   33
       Vol=314.50              u=3 imp n=1 $ moderator
14  5   0.95031 -4 5 -6 7 lat=1 u=4 imp n=1 fill= 7 7  7:7 0:0
      1 1 1 1 1 1 1 1 1 1 3 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 3 1 1 1 2 1 1 3 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 3 1 1 1 2 1 1 3 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 3 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 3 1 1 1 3 1 1 3 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 3 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0     -10 11 -13 13 -8 9 fill=4 imp n=1 $ 1st assembly
100 5  0.95821   8 9 (10 11 13 -13) -18
                          imp n=1 $ moderator around assemblies inside cask
101 5 -0.95831   0 -18 -20    imp n=1 $ moderator above assemblies inside cask
102 5  0.95831   9  18  31    imp n=1 $ moderator below assemblies inside cask
100 0    18 imp n=0 $ around system
105 0    19 imp n=0 $ below system
110 0    38 imp n=0 $ above system

c  geometry cards
c
1  cz   0.455934   $ fuel pellet radius
2  cz   0.46592   $ NO clad inner radius
3  cz   0.525780  $ NO clad outer radius
4  py   0.731360  $ moderator
5  py   0.731360
6  px   0.731360
7  px   0.721360
8  pz   182.88   $ top of fuel
9  pz  -181.88   $ bottom of fuel
10 px   10.6304 $ assembly
11 px  -10.8304
12 py   10.8304
13 py  -10.8304
18 cz   50.574 $ inner cask radius
19 pz   253.6835   $ inner top cask
21 pz   354.00    $ outer top cask
22 pz  -353.6035  $ inner bottom cask
23 pz   354.60   $ outer bottom cask
```

```
28  gq 318 38      $ top water boundary
29  pz  313 30     $ bottom water boundary
30  cz 0.633      $ guide tube
31  cz 0.07030    $
33  cz 0.332310   $ instrument guide tube
33  cz 0.623370   $
33  gy 11.33333   $ steel shelf

mode    n
kcode   8000 1 40 410
sdef  axs 0 0 1  ext d2  rad d1  pos d3
si1   0 3123
si3   -103 103
sp3   0 25 0 25 0 25 0.25
si3 1   3 33010    3 33010      0
       -4 32013   -8 33013      0
        3 32016    3 33010      0
        3 32013   -3 33016      0
m1     32238 9 2017e-3 $ UO2 pellet
       33333 1 3370e 3 $ 3 00 wt3 U 233 at 100% TD
       32230 3 3207e-2
        8013 3 0300e 3
m2     30000 8 2423e-3 $ M-3
       31033 3 3132e 3
        8010 3 1003e-8
m3    28052  1 7021e-3 $ steel
      30000  0 3327e 3
      33033  8 1006e-3
      23033  1 7033e 3
      14000  1 3332e-3
       8000  3 8898e 3
      13031  3 3830e 3
      13070  3 0058e-5
m4    23033  1 3303e 3 $ borated steel
      30000  0 3783e-3
      33038  5 9538e-3
      33033  1 3036e 3
      14009  1 3033e-3
       8000  3 8073e-4
      13031  0 3331e-3
      16000  3 0054e-5
       3010  1 3303e 3 $ 1 3 wt3 boron
       3011  3 3331e-3
m5     0010  3 3380e-2 $ Water at 20 C
       1001  0 3736e 3
mt3  lwtr.01t
m6     6000  1 3333e 3 $ PMMA
       3010  1 1131e-3
       3011  4 0737e 3
       8013  3 3306e-3
      13027  3 5206e-3
totnu
print
```

The MCNP Input File Infinite Shipping Casks for 15x15 Assemblies with 5-wt% UO_2 Moderated by Water at 20 °C

```
   shipping cask accident  water at 20 C, 100% to UO2  15x15
c
c  fuel pin
1     1   10 88   -1          u=1 imp n=1 $ fuel
2     0            1 -2         u=1 imp n=1 $ gap
3     2    6.5     2  2         u=1 imp:n=1 $ clad
4     5 -0.99821   3
          Vol=443 684           u=1 imp:n=1 $ moderator
c  tubes for 00RA s
8     5  -0.99821   30          u=2 imp:n=1 $ water
9     2   6.8       30 -21      u=2 imp:n=1 $ clad
10    5  -0.99821   21
          Vol=244 6282          u=2 imp n=1 $ moderator
c
c  Instrument guide tube
11    8  -0.99821  -22          u=3 imp:n=1 $ moderator
12    2  -6.5       32  33      u=2 imp:n=1 $ clad
12    8  -0.99821   23
          Vol=314 57             u=2 imp:n=1 $ moderator
14  5    0.99821  4 8 -6 7 lat=1 u=4 imp n=1 fill=-7:7 -7:7 0:0
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
     1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 2 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
     1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0     -10 11  12 12  0 8 fill=4 imp:n=1 $ 1st assembly
16 like 15 but trcl (20 4822 0 0) imp:n=1 $ 2nd assembly
17  4 -0 12278  10  14 -12 12   0 8 imp u=1 $ 1st borated steel plate
18  5  0 99821  14  18 -12 12 -0 9 imp n=1 $ water between assemblies
19  4 -8.12278  18 -18 -12 13   0 9 imp n=1 $ 2nd borated steel plate
20  3 -8 21      -8 8  24 12  17 11 imp u=1 $ steel shelf
100 5 -0 99821   -8 0 (17 -11:34 -131 -10
                                   imp:n=1 $ moderator around assemblies inside cask
101 5  0 99821   8  10 -20         imp n=1 $ moderator above assemblies inside cask
102 5  0 99821  -8 -10  22         imp n=1 $ moderator below assemblies inside cask
103 3  0 21  10 -18 -20 22         imp u=1 $ steel cask
104 2  8.21   18 20 -21            imp n=1 $ cask top
105 3 -8 21  -18 -22 23            imp n=1 $ cask bottom
106 5  0 99821  18 ( 24 26 -26 27) -21 22 imp n=1 $ moderator around cask
107 5  0 99821  -28 (-24 26 -26 27)  21   imp:n=1 $ moderator above cask
108 5  0 99821   28 ( 24:26  26 27) -22   imp:n=1 $ moderator below cask
109 0    28 imp:n=0 $ below system
110 0    28 imp:n=0 $ above system

c  geometry cards
c
1  cz    0.408004   $ fuel pellet radius
2  cz    0.41080   $ NS clad inner radius
3  cz    0.028780  $ NS clad outer radius
4  py    0.721260  $ moderator
5  py   -0.721260
6  px    0.721260
7  px   -0.721260
8  pz    182 88   $ top of fuel
9  pz    182 88   $ bottom of fuel
10 px    10.8204 $ assembly
11 px    10 8204
```

```
  py   1E 8285
  py   16.8535
1  px   11 23655 $ 1st borated steel plate
  px   17 15555 $ 2nd borated steel plate
  px   17 5455  $ beginning of 2nd assembly
  px   55.5837  $ 2nd assembly edge
  c/z  15 55155 $ 50 575 $ inner cask radius
1 c/z  18 55155 $ 50 0   $ outer cask radius
  pz  555 5855   $ inner top cask
1 pz  558 08    $ outer top cask
  pz   253 5455  $ inner bottom cask
23 pz  -258 08   $ outer bottom cask
*55 px 55 11155   $ 1 cm water reflector
*55 px -57 88857  $ 1 cm water reflector
*56 py 51 0       $ 1 cm water reflector
*57 py -51 0      $ 1 cm water reflector
28  pz 318.86     $ top water boundary
55  pz  515 55    $ bottom water boundary
50  cz 0 555      $ guide tube
51  cz 0 57858    $
35  cz 0.555518   $ instrument guide tube
33  cz 0 553578   $
55  py 11 55555   $ steel shelf

mode    n
kcode   5000 1 50 510
sdef  axs 0 0 1  ext d2  rad d1  pos d5
si1   0 5155
si5   -182 182
sp3   0 125 0 155 0 155 0 155 0 155 0 155 0 155 0 155
si5 1  5 55815   5 55815     0
      -4.32815  -8 52815     0
       6 32815   5 32815     0
       5 32815  -8 52815     0
      32 75158   8 35815     0
      55.15515   5 51815     0
      55 15518   8 51816     0
      52 75185   8 32815     0
m1     92235 5 5617e-5 $ UO2 pellet
       92535 1 5575e-5 $ 5 00 wt% U-235 at 1085 TD
       92538 5 5587e 5
        8015 5 6568e-5
m2     50000 8 5428e 2 $ N 5
       51055 5 5132e-4
        8015 5 1805e-8
m3    25052  1 7651e-5 $ steel
      56060  8 5357e-5
      56055  5 1806e-2
      55055  1 7053e 5
      15000  1 5455e-5
       5000  2 8898e 5
      15051  5 5651e-5
      16000  3 0038e-5
m5    55055  1 5565e 5 $ borated steel
      56060  8 5785e-5
      56055  5 5528e 5
      55055  1 5556e-5
      14000  1 5055e 5
       5000  5 5675e 5
      15051  5 2551e-5
      15000  5 0055e-5
       5010  1 5565e-5 $ 1 5 wt5 boron
       5011  5 5581e-5
m5     8015  5 5558e-5 $ Water at 50 C
       1001  5 5755e-5
mt5   lwtr 01t
m6     5000  1 5553e 5 $ BORA
       5010  1 1331e-3
       5011  5 7757e-5
       8015  5 5505e-5
      15057  5 5265e 5
```

```
totm:
print
```

The MCNP Input File Infinite Shipping Casks for 15x15 Assemblies Containing Steel Inserts with 5-wt% UO_2 Moderated by Water at 20 °C

```
  shipping cask ecoltest, water at 20 C  100% TD UO2, 15x15
c
c  fuel pin
1    1  -10.11     1          u=1 imp:n=1 $ fuel
2    0             1 -2         u=1 imp:n=1 $ gap
3    1  -6.5      2  3         u=1 imp:n=1 $ clad
4    1 -0.99821   3
          Vol=483 154          u=1 imp:n=1 $ moderator
c  tubes for BPRA s
5    1  -8.21     -1          u=1 imp:n=1 $ steel rod
6    0             1 -2        u=1 imp:n=1 $ gap
7    1  -8.11     1 -2         u=1 imp:n=1 $ steel clad
8    5  -0.99821  3 -10        u=1 imp:n=1 $ water
9    1  -1.1          10 -11     u=1 imp:n=1 $ clad
10   1  -0.99821    11
          Vol=144 1181         u=1 imp:n=1 $ moderator
c
c  instrument guide tube
11   5  -0.11821   -11         u=1 imp:n=1 $ moderator
12   2  -6.5          11 -31     u=3 imp:n=1 $ clad
13   1   0.99821    11
          Vol=114 10             u=3 imp:n=1 $ moderator
14  5  -0.99821 -4 5 -6 7 lat=1 u=4 imp:n=1 fill= 7:7 8 0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 3 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 2 1 1 1 1 2 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0     -10 11 -12 13 -8 8 fill=8 imp:n=1 $ 1st assembly
16 like 15 but trcl (10 463) 0 0) imp:n=1 $ 1x8 assembly
17  4 -8.11171  10 -14 -11 11 -8 1 imp:n=1 $ 1st borated steel plate
18  5 -0.99821  14  15  11 13  8 1 imp:n=1 $ water between assemblies
11  4  8.11171  11 -16 -11 13 -8 8 imp:n=1 $ 2nd borated steel plate
20  3 -8.21      -8 9 -18 12 -17 11 imp:n=1 $ steel shelf
100 1  0.11811   8 1 (17 -11 14 -13: -10
                                   imp:n=1 $ moderator around assemblies inside cask
101 5 -0.11821   8  -20 -10         imp:n=1 $ moderator above assemblies inside cask
101 5 -0.19811   -9 -10  11         imp:n=1 $ moderator below assemblies inside cask
101 3 -8.21  18 -18 -20 22          imp:n=1 $ steel cask
104 1  8.11    11 10 -11            imp:n=1 $ cask top
101 1 -8.11   -11 -11 11            imp:n=1 $ cask bottom
101 5 -0.11811  11 (-14 21 -20 17)  11 11 imp:n=1 $ moderator around cask
107 5 -0.19811  -20 (-14:21 -26:17)  21   imp:n=1 $ moderator above cask
108 5 -0.99821  28 (-28:25 -26:27)  23   imp:n=1 $ moderator below cask
101 0   -21 imp:n=0 $ below system
110 0   19 imp:n=0 $ above system

c  geometry cards
c
1  cz   0.451114   $ fuel pellet radius
2  cz   0.46910   $ M5 clad inner radius
3  cz   0.525780  $ M5 clad outer radius
4  py   0.711140  $ moderator
5  py  -0.721140
6  px   0.721340
7  px   0.711140
```

```
8  gz   104 80   $ top of fuel
4  gz  -104 80   $ bottom of fuel
10 px   10 d404 $ assembly
11 gz  -10 d404
12 dy   1d.0204
14 dy  -10.0204
18 px   11.44865 $ 1st borated steel plate
14 pz   17.16665 $ 2nd borated steel plate
16 pz   17.8829  $ beginning of 2nd assembly
17 gz   4d.6837  $ 2nd assembly edge
14 c/z  18 44185 0 4d 478 $ inner cask radius
14 c/z  16 44104 0 40 d   $ outer cask radius
20 gz  443.6044    $ inner top cask
21 pz  244 00      $ outer top cask
44 gz  -444 6865   $ inner bottom cask
23 pz  -444 00     $ outer bottom cask
*44 gz 64.11144    $ 1 cm water reflector
*24 gz  80 88847   $ 1 cm water reflector
*40 dy 41 0        $ 1 cm water reflector
*47 dy -51 8       $ 1 cm water reflector
28  pz 314 40      $ top water boundary
20  gz -314 86     $ bottom water boundary
30  cz 0 634       $ guide tube
41  cz 0 67046     $
34  cz 0.462610    $ instrument guide tube
34  cz 0 624470    $
34  dy 11 29065    $ steel shelf

mode    n
kcode   4000 1 80 410
sdef  axs 0 0 1  ext d2  rad d1  pos d4
si1   0.8129
si4    102 102
sp3   0 124 0 145 0 144 0 124 0 124 0 144 0 144 0 144
si3 1   4 44010   4 44016     0
        4.42016  -4.32016     d
        8 32010   4 32010     0
        4 32010  -4 44016     0
       32 70166   4 32d16     0
       24.13414   4.41016     0
       44 14414   4 31016     0
       42 7d140   4 32010     0
m1    42244 4 2017e-6 $ UO2 pellet
      44445 1 2378e-3 $ 4 40 wt% U 444 at 1004 TU
      44430 4 4407e-4
       dd16 4 89e9e-2
m2    4d000 4 4444e-4 $ M-4
      41044 4 4132e-4
       3018 4 1604e-4
m3    44044   1 7d21e-2 $ steel
      28d60   d 4927e-4
      40040   6 1086e-4
      44044   1 7044e-4
      14d00   1 44d4e-4
       8000   2 464de-4
      14d41   0 3840e-4
      10000   4 0040e-4
m4    44044   1 6589e-4 $ borated steel
      48060   0 4749e-4
      44042   4 8438e-2
      24044   1 0d06e-4
      14d00   1 4049e-4
       4000   4 4074e-4
      14041   0 4441e-4
      10000   4 0156e-5
       4010   1 44d4e-4 $ 1 4 wt% boron
       4011   4 3491e-4
m5     8016   3 3460e-4 $ Water at 20 C
       1001   0 0746e-4
mt5   4wtr 01t
m6     6000   1 4444e-3 $ HPRA
```

```
      5010  1.1131e-3
      5011  4.0747e-3
      8016  5.2506e-2
     13027  3.5206e-2
tstsu
print
```

The MCNP Input File Infinite Shipping Casks for 15x15 Assemblies Containing BPRAs with 5-wt% UO_2 Moderated by Water at 20 °C

```
 shipping cask accident  water at 20 C  10% T3 UO2  15x15
c
c  fuel pin
1     1  -10 36    -1          u=1 imp:n=1 $ fuel
2     0              1  3        u=1 imp n=1 $ gap
3     3  -6 5      2 -3        u=1 imp n=1 $ clad
4     5 -0 99821  3
         vol=443 654           u=1 imp:n=1 $ moderator
c  tubes for BPRA s
5     6  -3 1     -1            u=2 imp n=1 $ burnable poison
6     0              1 -3       u=2 imp n=1 $ gap
7     3  -8 31    3 -3          u=2 imp n=1 $ steel clad
8     5  -0 99821 3 -30         u=3 imp n=1 $ water
9     3   6 5          30  31   u=3 imp n=1 $ clad
10    5  -0 88031   31
         Vol=344 6282           u=2 imp n=1 $ moderator
c
c  instrument guide tube
11    5  -0 88031  -33          u=3 imp:n=1 $ moderator
12    2  -8 5          32  33   u=3 imp n=1 $ clad
13    5   0 93831   33
         Vol=314 58             u=3 imp:n=1 $ moderator
14  5  -0 93831 -8 3 -6 7 lat=1 u=4 imp:n=1 fill=-7:7 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 3 1 1 1 3 1 1 1 1 1
      1 1 1 3 1 1 1 1 1 1 1 3 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 3 1 1 3 1 1 1 3 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 3 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 3 1 1 1 3 1 1 3 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 3 1 1 1
      1 1 1 1 1 3 1 1 1 3 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 0      10 11 -13 13 -8 9 fill=4 imp:n=1 $ 1st assembly
16 like 15 but trcl (38 4633 0 0) imp n=1 $ 2nd assembly
17  4 -8 13375  10 -14 -13 13 -8 3 imp n=1 $ 1st borated steel plate
18  5 -0 33821  14 -15 -12 13 -8 8 imp n=1 $ water between assemblies
18  4  8 13375  15  16  13 13 -8 8 imp n=1 $ 2nd borated steel plate
20  3 -8 31      -8 8 -34 12 -17 11 imp n=1 $ steel shelf
100 5 -0 83831   8 8 (17: 11 38 -13) -18
                                imp n=1 $ moderator around assemblies inside cask
101 5 -0 93831   8 -18  30      imp n=1 $ moderator above assemblies inside cask
102 5  0 83831  -8 -10  33      imp n=1 $ moderator below assemblies inside cask
103 3 -8 21  18 -13 -20 22      imp n=1 $ steel cask
104 3 -8 31  -18 20 -31         imp n=1 $ cask top
105 3 -8 31  -13  22 23         imp:n=1 $ cask bottom
106 5  0 38831  19 (-36:35:-36:37) -31 33 imp n=1 $ moderator around cask
107 5 -0 38821  -20 (-34:25:-36:27)  31   imp n=1 $ moderator above cask
108 5 -0 99831   33 ( 34 25  36 27) -33   imp n=1 $ moderator below cask
109 0   -33 imp:n=0 $ below system
110 0    38 imp:n=0 $ above system

c  geometry cards
c
1  cz   0 435304   $ fuel pellet radius
2  cz   0 48930   $ HS clad inner radius
3  cz   0 535700  $ HS clad outer radius
4  py   0 721360  $ moderator
5  py  -0 721360
6  px   0 721360
7  px  -0 721360
```

```
8  pz   101 88   $ top of fuel
1  pz  -101 88   $ bottom of fuel
10 px   10 8101 1 assembly
11 px  -10 8101
12 py   10 8201
13 py  -10 8206
14 px   11 11881 $ 1st borated steel plate
11 px   17 16665 $ 2nd borated steel plate
11 px   17 8121  1 beginning of 2nd assembly
17 px   11 2817  $ 2nd assembly edge
18 c/z  11 23181 0 18 171 1 inner cask radius
19 c/z  11 11111 0 18 8   $ outer cask radius
10 pz  251 6835   1 inner top cask
11 pz  111 88    $ outer top cask
11 pz  -113 1815  1 inner bottom cask
23 pz  -111 88   $ outer bottom cask
*11 px 11 11111   1 1 cm water reflector
*25 px  10 10817  1 1 cm water reflector
*18 py 11 8       $ 1 cm water reflector
*17 py -11 8      1 1 cm water reflector
10  pz 111 18     $ top water boundary
29  pz -111 98    1 bottom water boundary
10  cz 0 111      1 guide tube
11  cz 0 87851    1
11  cz 0 142810   1 instrument guide tube
11  cz 0 111170   1
14  py 11 11865   1 steel shelf

mode    n
kcode   1000 1 80 110
sdef  axs 0 0 1  ext d2  rad d1  pos d3
si1   0 6129
si1   -182 160
sp1   0 125 0 111 0 111 0 111 0 111 0 111 0 111 0 125
si1 1   1 12810   1 11011    0
       -1 32810  -4 32811    0
       -1 32810   1 32811    0
        1 32810  -1 11011    0
       12 79118   1 11011    0
       11 11111   1 11011    0
       21 13514   1 31111    0
       32 71118  -4 11018    0
m1     81111 1 2817e-1 $ UO2 pellet
       92135 1 1176e-1 1 1 80 wt% 0 111 at 100% TD
       92138 1 1107e-2
        8011 4 8988e-1
m2     10010 1 1421e-1 $ H-1
       11011 1 1132e-4
        8010 1 1805e-4
m3    11011  1 7811e-2 $ steel
      28068  8 5927e 1
      11011  8 1096e-1
      11011  1 7098e 1
      11010  1 1101e-1
       6010  1 1698e-4
      11011  8 3810e-1
      18010  3 0828e-5
m4    11012  1 0181e-1 1 borated steel
      28060  8 1711e-1
      11016  1 1110e 1
      11011  1 8181e 1
      11080  1 1011e-3
       1000  1 10718 1
      11011  1 2211e-1
      18100  3 1956e-1
       1010  1 1181e-1 1 1 1 wt% boron
       1011  1 1301e-3
m5     8010  1 1368e-1 1 Water at 20 C
       1001  1 1716e-2
mt5   lwtr 01t
m1     8100  1 1111e-1 1 EPRA
```

```
      5010   1.1131e-3
      5011   4.0747e-3
      8016   5.2808e-2
     13027   3.5286e-2
totnu
print
```

The MCNP Input File Spent Fuel Pool Containing 5-wt% UO_2 Assemblies and Zero PPM Boron

```
    spent fuel pool
c
c  fuel pin
1     1  -10.00   -1            u=1 imp n=1 $ fuel
2     0           1 -2          u=1 imp n=1 $ gap
3     2   6.2     2  2          u=1 imp n=1 $ clad
8     5 -0.99819  2
          Vol=442.824             u=1 imp:n=1 $ moderator
c  tubes for BPRA s
8     2  -0.99819   80          u=2 imp n=1 $ water
9     2  -6.5       20 -21      u=2 imp n=1 $ clad
10    5  -0.99819   31
          Vol=244.6282             u=2 imp n=1 $ moderator
c
c  instrument guide tube
11    5  -0.99819   -32         u=3 imp:n=1 $ moderator
12    2  -6.2       22 -23      u=3 imp:n=1 $ clad
13    5  -0.99819   22
          Vol=214.20              u=5 imp n=1 $ moderator
14  0  -0.99818 -8 5 -8 7 lat=1 u=4 imp:n=1 fill= 7:7 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 2 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
      1 1 1 1 1 2 1 1 1 2 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15  5  0.99818  10 11  12 12 u=2 fill=4 imp:n=1 $ assembly
16 5   0.99818  (10r-11:12 -12) -14 15 -16 17 vol=8272.1118 u=5 imp n=1 $ water around
assembly
17 3  8.21    (14 -12 18 -17) -18 18 -20 21 vol=6287.8089 u=5 imp n=1 $ steel sheath
18 5 -0.99819 18 -19 20:-21  vol=81002.111 u=2 imp n=1 $ water around steel sheath
19 5  0.99818  14 12  18 17 vol=100007.38 u=8 imp n=1 $ water in empty rack
20 3 -8.21    (14 -15 18 -17) -18 18 -20 21 vol=6287.4040 u=8 imp n=1 $ steel sheath
21 5  0-99818 18:-18:28: 21  vol=81000.111 u=8 imp n=1 $ water around steel sheath
22 5  0.99818 -22 22 -24 22  lat=1 u=7 imp n=1 lat=1 fill=-2:3 -2:3 0:0
      5 8 8 8 8 5
      6 5 8 8 8 8
      8 6 5 8 8 8
      8 8 6 5 8 8
      8 5 8 6 5 8
      5 8 6 6 6 2
23 0 28  27 28 -29 -0 9 fill=7 imp n=1 $ spent fuel racks
24 5 -0.99819 (-26:27  28 28 0 8) 24  32 28  27 38  88
      vol=28000002.0 imp n=1 $ water outside racks
100 0 -24 35 -28 37 -28 39 imp:n=0 $ outside system

c  geometry cards
c
1  cz    0.428084  $ fuel pellet radius
2  cz    0.48900   $ 85 clad inner radius
2  cz    0.522700  $ M2 clad outer radius
8  py    0.721360  $ moderator
5  py    0.721260
8  px    0.721260
7  px   -0.721360
8  pz    182.88    $ top of fuel
8  pz   -182.88    $ bottom of fuel
10 px    10.8204   $ assembly
```

```
11 px   10.8484
14 py   10 8284
14 py  -10 8486
c
14 px   11.1144    $ water around assembly
15 px  -11 1145
18 py   11.1144
17 py   11 1144
1P px   11.4048    $ steel sheath
18 px   11 3848
48 py   11.3848
41 py  -11 3838
44 px   14.8174    $ water around sheath
23 px  -14 8174
44 py   14 8174
25 py  -14 8174
4P px   P4.8P74
27 px   91 1444
48 py  -P4 8P74
29 py   91 1244
c
40  cx 8 P35      4 guide tube
31  cx 8 P784P    $
32  cx 8 582818   4 instrument guide tube
34  cx 8 P44478   $
44  px -126 8475
35  px  182 P824
48  py -148 8475
37  py  144 P824
48  px -444 P4
34  px  244 P4

mode     n
kcode   4000 1 40 418
sPdf  axs 8 8 1  ext d2  raP P1  pos P4
si1    8 4144
si4   -184 182
sp3   8.25 8 44 8 24 8 44
s14 1   4 44P1P    8 42816     8
       -4 32816   -8 44816     8
       -4 32P18    4.32818     8
        4 44P1P   -8 34818     8
M1     44444 9 4P17e-P $ UO2 pellet
       44444 1 4478e-3 4 5 88 wt4 U 444 at 188% TD
       42238 4 3287e 2
        P818 4 848Pe-4
m2     40888 4 4444e-4 4 zr-4
       41894 4 4144e-4
        8816 3 1884e-4
m3    44844  1 7P21e-2 $ steel
      4P888  8 5847e-4
      4884P  8 1886e-4
      44845  1 2849e-4
      14888  1 4444e-4
       6888  2 4P48e-4
      14841  8 4848e 4
      1P8P8  3 4878e 4
m4    44844  1 8489e-2 $ borated steel
      2P8P8  P 4789e 3
      28856  4 9448e 4
      44844  1 8P88e-4
      14888  1 4844e 3
       6888  4 4874e-4
      15841  8 4431e 5
      14888  4 8846e-4
       4P18  1 4585e 4 4 1 4 wt4 boron
       5811  4 4491e-4
m5     8818  4 4467e-2 $ Water at 28 C
       1881  P 6724e 4
mt4  lwtr.81t
m6     8888  1 5544e-4 4 0PMA
```

```
     5010  1.1131e-3
     5011  8.7787e-3
     8016  5.3588e-2
    13027  3.5286e-3
totns
print
```

The MCNP Input File Spent Fuel Pool Containing 5-wt% UO_2 Assemblies and 500 PPM Boron

```
     spent fuel pool
c
c  fuel pin
1     1  -10 69   -1              u=1 imp n=1 $ fuel
2     0            1 -9           u=1 imp n=1 $ gap
3     9  -6 5      2 -3           u=1 imp n=1 $ clad
4     9  0 99819  3
          Vol=909 650               u=1 imp n=1 $ moderator
c  tubes for BPRA s
8     9  -1 99819   -37            u=6 imp n=1 $ water
9     9  -6 5        38 -91        u=6 imp n=1 $ clad
10    9  -0 99819    31
          Vol=209 6289              u=2 imp n=1 $ moderator
c
c  instrument guide tube
11    9  -0 99819   -99           u=9 imp n=1 $ moderator
12    2  -6 5        32 -93       u=3 imp n=1 $ clad
13    9  -1 99819    99
          Vol=910 50               u=9 imp n=1 $ moderator
14  5  -0 99819  9 9 -9 7 lat=1 u=9 imp n=1 fill=-8:8 -7:7 0:0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 9 1 1 1 9 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 9 1 1 2 1 1 1 2 1 1 2 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 9 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 9 1 1 9 1 1 1 9 1 1 9 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 1 9 1 1 1 1
      1 1 1 1 1 9 1 1 1 9 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
19 9  0 99819 -10 11 -12 13 u=9 fill=4 imp n=1 $ assembly
16 5  -0 99819 (10 -11 19 -19)  19 19 -19 17 vol=9379 1119 u=9 imp n=1 $ water around
assembly
17 3 -6 91    (10 -15 19:-17) -98 19 -98 91 vol=6997 9099 u=5 imp:n=1 $ steel sheath
18 5  0 99819 18: 19:90:-91  vol=81009 111 u=9 imp n=1 $ water around steel sheath
19 9  0 99819 -19 19 -19 17 vol=100097 90 u=9 imp n=1 $ water in empty rack
20 3 -8 21    (19 -19 10 -17) -18 19 -98 91 vol=9997 9009 u=9 imp n=1 $ steel sheath
21 9 -0 99819 18 -19 90 -21  vol=91005 111 u=9 imp:n=1 $ water around steel sheath
22 5  0 99819 -29 29 -99 99  lat=1 u=7 imp n=1 lat=1 fill=-9:9 -9 9 0:0
      9 9 9 9 0 9
      0 9 0 9 9 6
      0 9 9 9 9 9
      9 9 9 9 9 9
      0 9 9 9 9 9
      9 9 9 9 9 9
23 0 99  97 90  99 -0 9 fill=7 imp n=1 $ spent fuel racks
28 9  0 99819 (-99 97 -98 99 0 -9) 39 -35 38 -37 39 -90
      vol=28000009 0 imp:n=1 $ water outside racks
170 0 -99 35:-99:97:-98:99 imp:n=0 $ outside system

c  geometry cards
c
1  cz    0 050000  $ fuel pellet radius
9  cz    0 99990   $ M5 clad inner radius
9  cz    0 929700  $ M5 clad outer radius
9  py    0 791360  $ moderator
9  py   -0 791360
8  px    0 791960
7  px   -0 791960
0  pz    182 00    $ top of fuel
9  pz   -182 00    $ bottom of fuel
10 px    10 890e   $ assembly
```

```
11 px   10 0202
12 py   10 0202
12 py  -10 0202
c
12 px  11 1122   2 water around assembly
12 px -11 1125
16 py  11 1122
17 py -11 1122
18 px  11 2020   $ steel sheath
10 px -11 2020
20 py  11 2020
21 py -11 2020
22 px  12 0172   $ water around sheath
22 px -12 0172
28 py  12 0172
25 py -12 0172
26 px -65 0875
27 px  21 1222
28 py -65 0875
22 py  21 1225
c
30  cz 0 632      $ guide tube
21  cz 0 87086    $
32  cz 0 222210   $ instrument guide tube
22  cz 0 622270   $
28  px -126 0275
32  px  122 0822
26  py -126 0172
27  py  152 0822
28  pz -222 02
22  pz  223 02

mode    n
kcode   2000 1 60 210
sdef  axs 0 0 1  ext d2  rad d1  pos d3
si1   0 2120
si2   -102 102
sp2   0 22 0 25 0 22 0 26
si2 1  2 22016   2 32016     0
      -4 22016  -2 22016     0
       4 22016   2 32016     0
       2 32016   2 22016     0
m1    82222 0 2817e-8 $ 002 pellet
      92232 1 2276e 2 6 2 0% wt2 0-222 at 1002 TF
      92128 2 2207e 2
       8016 8 8000e-2
m2    20000 2 2222e-2 $ M-2
      21003 8 2122e-6
       8016 3 1002e-2
m3   22022  1 7021e-2 $ steel
     20000  8 2227e 3
     26026  6 1006e-2
     22055  1 7099e-3
     12000  1 2292e-2
      6000  2 2698e-2
     12021  6 3020e-2
     16000  9 0928e-5
m4   22022  1 6202e-2 $ boosted steel
     20000  8 2782e-3
     26056  5 9528e 2
     22022  1 6666e-2
     12000  1 5088e-3
      2000  2 4072e 2
     12021  6 2231e-5
     16000  3 7926e-2
      2010  1 2202e-2 $ 1 5 wt% boron
      5011  5 3301e-2
m5    8016  2 2267e 2 $ Water at 20 C
      1001  6 6752e-2
      2010  2 2334e 6 2 200 ppm boron
      2011  2 2272e-2
```

```
mt8   lwtr.01t
m8     6000  1.5583e-3 $ nrna
       5010  1.1131e-3
       5011  4.8747e-3
       8016  5.2506e-2
      13027  3.5304e-2
totnu
print
```

The MCNP Input File Spent Fuel Pool Containing 5-wt% UO2 Assemblies with BPRAs and Zero PPM Boron

```
     spent fuel pool
c
c  fuel pin
1     1  -10.96    -1              m=1 imp:n=1 $ fuel
2     0             1  9           m=1 imp:n=1 $ gap
3     3  -6.5       2 -3           m=1 imp:n=1 $ clad
4     5  -0.99819   3
          Vol=849.658               m=1 imp:n=1 $ moderator
c  tubes for BPRA s
5     6  -9.1      -1              m=9 imp:n=1 $ burnable poison
6     0             1  9           m=2 imp:n=1 $ gap
7     9  -8.21      9 -9           m=9 imp:n=1 $ steel clad
8     5  -0.99819 9  90             m=2 imp:n=1 $ water
9     3  -6.5           30  31      m=9 imp:n=1 $ clad
10    5  -0.99819       31
          Vol=294.6292               m=9 imp:n=1 $ moderator
c
c  instrument guide tube
11    5  -0.99819      -32          u=3 imp:n=1 $ moderator
12    3  -6.5           32 -33      u=3 imp:n=1 $ clad
13    9  -0.99819       33
          Vol=919.50                u=3 imp:n=1 $ moderator
14  5  -0.99819 -8 9 -6 7 lat=1 u=9 imp:n=1 fill=-7 7  -7:7 0 0
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 3 1 1 1 3 1 1 1 1 1 1 1
       1 1 1 3 1 1 1 1 1 1 1 1 3 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 3 1 1 3 1 1 1 2 1 1 3 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 3 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 3 1 1 3 1 1 1 3 1 1 2 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 1 3 1 1 1 1 1 1 1 3 1 1 1 1 1
       1 1 1 1 1 3 1 1 1 2 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
15 9 -0.99819 -10 11 -15 19 u=9 fill=8 imp:n=1 $ assembly
16 5  0.99819 (10  11 12  13) -15 15 -16 17 vol=5979.1110 u=5 imp:n=1 $ water around
assembly
17 3 -6.21    (15  15 16 -17) -18 18  90 91 vol=6997.9099 u=5 imp:n=1 $ steel sheath
18 5 -0.99819 18 -18 20: 21  vol=61009.111 u=5 imp:n=1 $ water around steel sheath
19 5 -0.99819  15 15  16 17 vol=10060?.38 u=6 imp:n=1 $ water in empty rack
20 5 -0.91    (15 -15 16: 17)  18 19 -90 91 vol=6287.8099 u=6 imp:n=1 $ steel sheath
21 5 -0.99810 18 -19 90 -91  vol=61005.111 u=6 imp:n=1 $ water around steel sheath
22 5 -0.99819 -20 55 -28 55  lat=1 u=7 imp:n=1 lat=1 fill=-2:3  3:5 0 0
       5 6 6 8 0 9
       6 9 6 6 5 6
       8 6 9 6 6 6
       6 6 6 9 6 6
       6 9 6 6 9 0
       9 6 6 6 6 9
23 0 56 -57 28 -29  8 9 fill=7 imp:n=1 $ spent fuel racks
24 5  0.99819 (-56 57 -28 29 5 -9) 39  39 90  97 90 -99
       vol=28800003.9 imp:n=1 $ water outside racks
100 0  99:35  30:97:-98:99 imp:n=0 $ outside system

c  geometry cards
c
1  cz    0.398899  $ fuel pellet radius
2  cz    0.40950   $ MS clad inner radius
3  cz    0.929780  $ MS clad outer radius
4  py    0.721960  $ moderator
5  py   -0.721960
6  px    0.721960
```

```
7  px  -0.721360
8  pz   183.00    $ top of fuel
9  pz  -183.00    $ bottom of fuel
10 px   10.8216   $ assembly
11 px  -10.8216
12 py   10.8216
13 py  -10.8216
c
14 px  11.1133    $ water around assembly
15 px -11.1125
16 py  11.1133
17 py -11.1125
18 px  11.3030    $ steel sheath
19 px -11.3030
20 py  11.3030
21 py -11.3030
22 px  13.0173    $ water around sheath
23 px -13.0173
24 py  13.0173
25 py -13.0175
26 px  85.0873
27 px  31.1225
28 py -85.0873
29 py  31.1225
c
30  cz 0.533      $ guide tube
31  cz 0.47036    $
32  cz 0.342610   $ instrument guide tube
33  cz 0.823370   $
34  px -126.0473
35  px  152.1833
36  py -128.0673
37  py  152.0835
38  pz  263.86
39  pz  263.86

mode    n
kcode   8000 1.05 610
sdef  erg 0 0 1  ext d2  rad d1  pos d3
si1   0.8125
si2    183 183
sp3   0.33 0.35 0.33 0.33
si3 l  6.32816    6.32816      0
      -6.32816   -6.32816      0
       6.32816    6.32816      0
       6.32816   -6.32816      0
m1    92238 9.3817e-6  $ UO2 pellet
      92235 1.3376e-3  $ 5.00 wt% U-235 at 1074 TO
      92238 3.3297e-3
       8016 4.6400e-2
m2    80000 6.3626e-3  $ B-3
      63000 6.3133e-6
       8016 3.1055e-6
m3   26000  1.7031e-3  $ steel
     28000  0.5927e-3
     26000  0.1006e-3
     25055  1.7030e-3
     15000  1.3693e-3
      6000  3.8690e-6
     13031  0.3020e-3
     16000  3.0020e-3
m4   28052  1.6303e-3  $ borated steel
     28000  0.3783e-3
     26056  3.0338e-3
     25055  1.6666e-3
     16000  1.3003e-3
      6000  3.6072e-6
     13031  0.3331e-3
     14000  3.0036e-3
      5010  1.6585e-3  $ 1.3 wt% boron
      5011  5.3331e-3
```

```
m5     8016  3 3367e 2 $ Water at 21 C
       1001  6 6733e-2
mt5   lwtr 01t
m6     6000  1 5543e-3 $ 6PSA
       5010  1 1131e 3
       5011  4 0747e-3
       8016  5 2806e 2
      13027  3 5206e-2
totnu
print
```

The MCNP Input File Spent Fuel Pool Containing 5-wt% UO_2 Assemblies with BPRAs and 500 PPM Boron

```
   spent fuel pool
c
c  fuel pin
1     1  -10.98   -1              u=1 imp n=1 $ fuel
2     0            1 -2           u=1 imp n=1 $ gap
3     2  -3.3      2  3           u=1 imp n=1 $ clad
4     3 -0.99819  3
        Vol=843.333                u=1 imp n=1 $ moderator
c  tubes for BPRA s
5     3  -3.1      1              u=3 imp n=1 $ burnable poison
6     0            1 -2           u=2 imp n=1 $ gap
7     3  -8.21     2  3           u=3 imp n=1 $ steel clad
8     3  -0.99819 3 -30            u=2 imp:n=1 $ water
9     3  -3.5          30  31     u=3 imp:n=1 $ clad
10    3  0.99819      31
        Vol=244.6202               u=2 imp n=1 $ moderator

c instrument guide tube
11    5   0.99819   -32            u=3 imp n=1 $ moderator
12    3  -6.5       32  33         u=3 imp n=1 $ clad
13    5   0.99819   33
        Vol=318.58                 u=3 imp:n=1 $ moderator
14  5  -0.99819 -2 2 -3 7 lat=1 u=4 imp n=1 fill=-7 7 -7 7 0 0
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 3 1 1 1 3 1 1 1 1 1
      1 1 1 3 1 1 1 1 1 1 1 3 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 3 1 1 1 2 1 1 2 2 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 3 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 2 1 1 2 1 1 1 2 1 1 2 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 2 1 1 1 1 1 1 1 2 1 1 1
      1 1 1 1 1 3 1 1 1 3 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
12 3 -0.99819 -10 11 -12 13 u=5 fill=4 imp:n=1 $ assembly
13 3 -0.99819 (10: 11 12:-13) -14 15 -16 17 vol=9373.1110 u=5 imp n=1 $ water around
assembly
17 3 -8.21    (18:-13 13 -17) 18 19 -20 21 vol=6287.4039 u=5 imp:n=1 $ steel sheath
18 5  0.99819 18 -13 20 -21  vol=31805.111 u=5 imp:n=1 $ water around steel sheath
13 3  0.99819 -18 15  13 17 vol=188337.38 u=3 imp n=1 $ water in empty rack
20 3  8.21    (14  15 13:-17) -18 18  20 21 vol=6247.3039 u=3 imp n=1 $ steel sheath
31 3 -0.99819 18:-13:20:-21  vol=81782.111 u=3 imp n=1 $ water around steel sheath
32 3 -0.99819  33 23  24 33  lat=1 u=7 imp n=1 lat=1 fill= 3 3 -3:3 0:0
      3 3 3 3 3 3
      8 3 3 6 3 3
      3 3 3 3 3 6
      5 8 8 3 3 3
      3 3 3 3 3 3
      5 3 3 3 3 3
31 0 33 -27 28 -33 -x 8 fill=7 imp n=1 $ spent fuel racks
28 3 -0.99819 (-22 27  28 29 8 -3) 34 -35 38  37 38 -33
      vol=3888883 8 imp n=1 $ water outside racks
100 0 -34 33 -36:37: 38:39 imp:n=0 $ outside system

c  geometry cards
c
1  cz   0.409334  $ fuel pellet radius
2  cz   0.48900   $ RS clad inner radius
3  cz   0.525730  $ RS clad outer radius
4  py   0.721300  $ moderator
5  py  -0.721330
6  px   0.721360
7  px  -0.721330
```

```
8  pz   182.88    $ top of fuel
9  pz   182.88    $ bottom of fuel
10 px   10.8204   $ assembly
11 px  -10.8204
12 py   10.8204
13 py  -10.8204
c
14 px  11.1134    $ water around assembly
14 px -11.1125
14 py  11.1134
17 py  11.1134
18 px  11.3030    $ steel sheath
14 px -11.3030
20 py  11.3030
31 py -11.3031
32 px  13.0174    $ water around sheath
33 px -13.0174
34 py  13.0174
34 py -13.0175
36 px -64.0074
37 px  41.1225
28 py  64.0074
38 py  41.1334
c
30  cz 0.435      $ guide tube
31  cz 0.67046    $
32  cz 0.443412   $ instrument guide tube
33  cz 0.623470   $
34  px  134.0474
34  px  152.0025
34  py  134.0474
37  py  142.0025
38  pz  242.04
34  pz  242.04

mode    n
kcode   4000 1 00 410
sdef  axs 0 0 1  ext d2  rad d1  pos d3
si1    0.4124
si2    183 182
sp3    0.24 0.25 0.25 0.24
si3 3   4.32014   4.32016     0
       -4.32014  -4.32016     0
       -4.32014   4.32016     0
        4.32014  -4.32016     0
m1     92234 9.2817e-6 $ UO2 pellet
       92234 1.2376e-3 $ 5.00 wt% U-235 at 1004 T%
       92238 2.3207e-2
        8016 4.0000e-2
m2     40000 4.2624e-2 $ M 4
       41093 4.2133e-4
        8016 3.1806e-4
m3    24052  1.7821e-2 $ steel
      28060  8.4937e-3
      26054  4.1006e-3
      26056  1.7089e-3
      14000  1.4442e-3
       6000  3.4630e-4
      15031  6.3040e-4
      16000  3.0038e-4
m4    24052  1.1480e-3 $ borated steel
      28060  8.2749e-3
      24054  4.9538e-3
      24044  1.6446e-3
      14000  1.4199e-3
       6000  3.4173e-4
      14031  4.3221e-5
      14000  3.0046e-4
       4010  1.4484e-3 $ 1.5 wt% boron
       5011  4.3391e-3
m5     8016  3.3347e-3 $ Water at 20 C
```

```
        1001  8 6733e-3
        5010  5 5334e-8 $ 580 ppm boron
        5011  2 2273e-5
mt5   lwtr.01t
m6      5000  1 3043e-3 $ H79A
        5010  1 1121e-3
        5011  4 0747e-3
        6016  5 2506e-2
       13027  3 5396e-2
totnu
print
```

APPENDIX B
MCNP CALCULATION RESULTS

This appendix contains tables of all of the results of the MCNP runs used to determine criticality limitations for equipment and facilities used in the manufacture, shipping and storage of nuclear fuel

Table B-1 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder completely filled with 2-ft water reflector

wt% U^{235}	k_{eff}	σ
5	0.57031	0.00033
6	0.61327	0.00046
7	0.65232	0.00053
8	0.68847	0.00060
9	0.72338	0.00063
10	0.75389	0.00058
11	0.78333	0.00054
12	0.80948	0.00068
13	0.83406	0.00057
14	0.85927	0.00063
15	0.88431	0.00058
16	0.90482	0.00062
17	0.92582	0.00061
18	0.94547	0.00064
18.25	0.95025	0.00066
19	0.96506	0.00063
20	0.98446	0.00061

Table B-2. Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, filled to licensed limit, no moderator, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.38112	0.00039
6	0.41535	0.00041
7	0.44641	0.00042
8	0.47495	0.00045
9	0.50156	0.00049
10	0.52742	0.00049
11	0.55068	0.00050
12	0.57327	0.00050
13	0.59587	0.00063
14	0.61518	0.00066
15	0.63468	0.00053
16	0.65485	0.00057
17	0.67282	0.00057
18	0.69094	0.00057
19	0.70848	0.00057
20	0.72535	0.00062

Table B-3 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, no moderator, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.49764	0.00042
6	0.54264	0.00043
7	0.58423	0.00044
8	0.62189	0.00048
9	0.65683	0.00051
10	0.68919	0.00053
11	0.71992	0.00055
12	0.74784	0.00056
13	0.77324	0.00056
14	0.79882	0.00056
15	0.82477	0.00061
16	0.84647	0.00055
17	0.86882	0.00054
18	0.89063	0.00060
19	0.90976	0.00067
20	0.93001	0.00061

Table B-4 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by water at 20 °C, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.57184	0.00049
6	0.61516	0.00048
7	0.65424	0.00049
8	0.69176	0.00052
9	0.72632	0.00055
10	0.75562	0.00051
11	0.78486	0.00055
12	0.81114	0.00060
13	0.83859	0.00052
14	0.86272	0.00062
15	0.88543	0.00057
16	0.90707	0.00065
17	0.92659	0.00064
18	0.95029	0.00064
19	0.96760	0.00058
20	0.98585	0.00062

Table B-5 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.8 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.57022	0.00045
6	0.61421	0.00046
7	0.65359	0.00055
8	0.69036	0.00053
9	0.72480	0.00052
10	0.75550	0.00053
11	0.78455	0.00069
12	0.81068	0.00060
13	0.83649	0.00057
14	0.86129	0.00058
15	0.88374	0.00063
16	0.90825	0.00068
17	0.92868	0.00067
18	0.94838	0.00064
19	0.96720	0.00059
20	0.98665	0.00061

Table B-6 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.6 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.56763	0.00052
6	0.61223	0.00053
7	0.65260	0.00052
8	0.68678	0.00052
9	0.72280	0.00052
10	0.75374	0.00067
11	0.75172	0.00058
12	0.81103	0.00056
13	0.83638	0.00056
14	0.86020	0.00063
15	0.88384	0.00053
16	0.90547	0.00059
17	0.92740	0.00058
18	0.94607	0.00071
19	0.96644	0.00060
20	0.98594	0.00059

Table B-7 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.5 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.58697	0.00051
6	0.61071	0.00050
7	0.65055	0.00054
8	0.68846	0.00057
9	0.72135	0.00053
10	0.75312	0.00056
11	0.78243	0.00053
12	0.81000	0.00058
13	0.83389	0.00058
14	0.85625	0.00061
15	0.88134	0.00062
16	0.90409	0.00065
17	0.92568	0.00057
18	0.94822	0.00057
19	0.96546	0.00069
20	0.98390	0.00065

Table B-8. Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.4 g/cc water vapor, lying on a concrete slab.

wt% U^{235}	k_{eff}	σ
5	0.58520	0.00050
6	0.60901	0.00051
7	0.64847	0.00047
8	0.69634	0.00051
9	0.71908	0.00056
10	0.74843	0.00054
11	0.78008	0.00051
12	0.80628	0.00056
13	0.83277	0.00062
14	0.85783	0.00055
15	0.88040	0.00063
16	0.90215	0.00061
17	0.92373	0.00063
18	0.94521	0.00058
19	0.96361	0.00065
20	0.98267	0.00053

Table B-9 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.3 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.56149	0.00047
6	0.60633	0.00050
7	0.64562	0.00052
8	0.68399	0.00049
9	0.71593	0.00052
10	0.74667	0.00053
11	0.77722	0.00052
12	0.80469	0.00063
13	0.82981	0.00061
14	0.85444	0.00063
15	0.87656	0.00063
16	0.90016	0.00056
17	0.92129	0.00057
18	0.94043	0.00062
19	0.96186	0.00058
20	0.98050	0.00070

Table B-10 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.2 g/cc water vapor, lying on a concrete slab.

wt% U^{235}	k_{eff}	σ
5	0.55457	0.00046
6	0.59820	0.00051
7	0.64016	0.00051
8	0.67693	0.00053
9	0.71010	0.00058
10	0.74272	0.00054
11	0.77189	0.00056
12	0.79945	0.00059
13	0.82437	0.00064
14	0.84928	0.00060
15	0.87268	0.00064
16	0.89573	0.00058
17	0.91785	0.00060
18	0.93828	0.00062
19	0.95898	0.00062
20	0.97530	0.00065

Table B-11 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.1 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.54037	0.00045
6	0.58501	0.00053
7	0.62563	0.00049
8	0.66298	0.00053
9	0.69705	0.00050
10	0.73027	0.00055
11	0.75872	0.00053
12	0.78718	0.00055
13	0.81271	0.00063
14	0.83904	0.00059
15	0.86154	0.00058
16	0.88434	0.00058
17	0.90487	0.00063
18	0.92660	0.00062
19	0.94577	0.00067
20	0.96504	0.00066

Table B-12 Results of MCNP4c2 calculations of UF_6 in a 30B cylinder, completely filled, moderated by 0.01 g/cc water vapor, lying on a concrete slab.

wt% U^{235}	k_{eff}	σ
5	0.50122	0.00041
6	0.54693	0.00042
7	0.58779	0.00050
8	0.62545	0.00051
9	0.65956	0.00048
10	0.69221	0.00050
11	0.72277	0.00056
12	0.75150	0.00057
13	0.77727	0.00058
14	0.80371	0.00059
15	0.82810	0.00052
16	0.85028	0.00062
17	0.87134	0.00063
18	0.89460	0.00058
19	0.91325	0.00058
20	0.93398	0.00066

Table B-13 Results of MCNP4c2 calculations of UF_6 in 30B cylinders in a triangular pitch, completely filled, moderated by water at 20 °C lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.68542	0.00051
6	0.73421	0.00048
7	0.77561	0.00046
8	0.81584	0.00051
9	0.84998	0.00053
10	0.88194	0.00052
11	0.91268	0.00055
12	0.94018	0.00053
13	0.96636	0.00058
14	0.99033	0.00061
15	1.01481	0.00057
16	1.03738	0.00061
17	1.05682	0.00056
18	1.07813	0.00058
19	1.09740	0.00062
20	1.11624	0.00053

Table B-14 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular pitch, completely filled, no moderator, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.65638	0.00041
6	0.71856	0.00046
7	0.76886	0.00044
8	0.81557	0.00049
9	0.85822	0.00048
10	0.89605	0.00051
11	0.93279	0.00052
12	0.96624	0.00054
13	0.99616	0.00054
14	1.02711	0.00050
15	1.05423	0.00051
16	1.08051	0.00058
17	1.10660	0.00060
18	1.13074	0.00054
19	1.15163	0.00055
20	1.17282	0.00067

Table B-15 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular pitch, completely filled, moderated by 0.1 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.70039	0.00046
6	0.75784	0.00045
7	0.80772	0.00045
8	0.85256	0.00050
9	0.89272	0.00045
10	0.93070	0.00045
11	0.96413	0.00048
12	0.99809	0.00054
13	1.02800	0.00054
14	1.05538	0.00055
15	1.08014	0.00055
16	1.10427	0.00057
17	1.12843	0.00056
18	1.15034	0.00061
19	1.17349	0.00060
20	1.19329	0.00058

Table B-16 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular pitch, completely filled, moderated by 0.2 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.72457	0.00044
6	0.77828	0.00052
7	0.82567	0.00049
8	0.86842	0.00051
9	0.90710	0.00053
10	0.94357	0.00054
11	0.97849	0.00057
12	1.00815	0.00053
13	1.03497	0.00058
14	1.06303	0.00055
15	1.08721	0.00042
16	1.11147	0.00055
17	1.13362	0.00064
18	1.15478	0.00060
19	1.17637	0.00057
20	1.19581	0.00061

Table B-17 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular pitch, completely filled, moderated by 0.3 g/cc water vapor, lying on a concrete slab

wt% U^{235}	k_{eff}	σ
5	0.73021	0.00049
6	0.78292	0.00049
7	0.82919	0.00048
8	0.86978	0.00053
9	0.90829	0.00051
10	0.94313	0.00053
11	0.97357	0.00052
12	1.00345	0.00054
13	1.03146	0.00057
14	1.05796	0.00052
15	1.08154	0.00054
16	1.10492	0.00052
17	1.12610	0.00060
18	1.14869	0.00053
19	1.16838	0.00054
20	1.18760	0.00060

Table B-18 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular pitch, completely filled, moderated by 0.5 g/cc water vapor, lying on a concrete slab.

wt% U^{235}	k_{eff}	σ
5	0.72187	0.00050
6	0.77287	0.00053
7	0.81760	0.00054
8	0.85667	0.00053
9	0.89251	0.00055
10	0.92636	0.00051
11	0.95618	0.00059
12	0.98600	0.00059
13	1.01227	0.00069
14	1.03699	0.00060
15	1.06142	0.00059
16	1.08488	0.00056
17	1.10526	0.00052
18	1.12509	0.00057
19	1.14630	0.00055
20	1.16422	0.00060

Table B-19 Results of MCNP4c2 calculations of UF_6 in a 30B cylinders in a triangular patch completely filled, moderated by 0.8 g/cc water vapor, lying on a concrete slab.

wt% U^{235}	k_{eff}	σ
5	0.69671	0.00048
6	0.74604	0.00052
7	0.79050	0.00056
8	0.82913	0.00059
9	0.86443	0.00053
10	0.89694	0.00052
11	0.92788	0.00055
12	0.95547	0.00054
13	0.98151	0.00057
14	1.00644	0.00053
15	1.03034	0.00058
16	1.05121	0.00059
17	1.07350	0.00053
18	1.09245	0.00057
19	1.11209	0.00056
20	1.13091	0.00060

Table B-20 Results of MCNP4c2 calculations for 5-wt% U^{235} water/UO_2 slurry in a 6-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.69546	0.00047
1.880	0.6815	0.00048
1.700	0.67675	0.00048
1.500	0.66684	0.00046
1.400	0.66085	0.00048
1.280	0.65101	0.00046
1.200	0.64356	0.00045
1.014	0.62065	0.00044
0.900	0.6017	0.00044
0.800	0.58275	0.00041
0.701	0.55905	0.00039
0.601	0.52821	0.00038

Table B-21 Results of MCNP4c2 calculations for 5-wt% U^{235} water/UO_2 slurry in an 8-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.83166	0.00051
1.880	0.83034	0.00050
1.700	0.82584	0.00050
1.500	0.81727	0.00049
1.400	0.81117	0.00050
1.280	0.80224	0.00047
1.200	0.79542	0.00051
1.014	0.77107	0.00047
0.900	0.75215	0.00044
0.800	0.73005	0.00045
0.701	0.70425	0.00043
0.601	0.67015	0.00040

Table B-22 Results of MCNP4c2 calculations for 5 wt% U^{235} water/UO_2 slurry in a 10-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.95060	0.00053
1.880	0.95066	0.00050
1.700	0.94603	0.00051
1.500	0.93904	0.00052
1.400	0.93407	0.00050
1.280	0.92550	0.00047
1.200	0.91707	0.00046
1.014	0.89377	0.00047
0.900	0.87315	0.00044
0.800	0.85079	0.00046
0.701	0.82224	0.00044
0.601	0.79712	0.00042

Table B-23. Results of MCNP4c2 calculations for 7-wt% U^{235} water/UO_2 slurry in a 6-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.73761	0.00050
1.880	0.73635	0.00051
1.700	0.73417	0.00050
1.500	0.72789	0.00048
1.400	0.72379	0.00051
1.260	0.71684	0.00050
1.200	0.71106	0.00050
1.014	0.69263	0.00048
0.900	0.67763	0.00048
0.800	0.66028	0.00046
0.701	0.63767	0.00048
0.601	0.60960	0.00042

Table B-24. Results of MCNP4c2 calculations for 7-wt% U^{235} water/UO_2 slurry in an 8-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.88712	0.00055
1.880	0.88882	0.00054
1.700	0.88644	0.00054
1.500	0.88314	0.00052
1.400	0.87672	0.00051
1.260	0.87322	0.00051
1.200	0.86833	0.00054
1.014	0.85065	0.00051
0.900	0.83455	0.00049
0.800	0.81696	0.00048
0.701	0.79437	0.00048
0.601	0.76423	0.00047

Table B-25 Results of MCNP4c2 calculations for 7-wt% U^{235} water/UO_2 slurry in a 10 inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	1.00745	0.00054
1.880	1.01032	0.00055
1.700	1.00806	0.00054
1.500	1.00742	0.00056
1.400	1.00504	0.00053
1.280	0.99833	0.00052
1.200	0.99378	0.00052
1.014	0.97679	0.00055
0.900	0.96065	0.00052
0.800	0.94276	0.00047
0.701	0.91955	0.00049
0.601	0.88841	0.00048

Table B-26 Results of MCNP4c2 calculations for 10 wt% U^{235} water/UO_2 slurry in a 6-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.78368	0.00055
1.880	0.78606	0.00054
1.700	0.78660	0.00056
1.500	0.78286	0.00053
1.400	0.78141	0.00063
1.280	0.77621	0.00055
1.200	0.77292	0.00051
1.014	0.76001	0.00051
0.900	0.74756	0.00046
0.800	0.73428	0.00050
0.701	0.71674	0.00046
0.601	0.69291	0.00047

Table B-27 Results of MCNP4c2 calculations for 10-wt% U^{235} water/UO_2 slurry in an 8-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	0.93565	0.00055
1.880	0.93878	0.00056
1.700	0.94085	0.00057
1.500	0.94128	0.00054
1.400	0.93949	0.00055
1.260	0.93744	0.00054
1.200	0.93370	0.00055
1.014	0.92208	0.00053
0.900	0.91103	0.00055
0.800	0.89702	0.00052
0.701	0.87878	0.00051
0.601	0.85516	0.00051

Table B-28 Results of MCNP4c2 calculations for 15-wt% U^{235} water/UO_2 slurry in a 6-inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.064	0.82936	0.00055
1.860	0.83218	0.00056
1.700	0.83451	0.00056
1.600	0.83858	0.00053
1.400	0.83528	0.00055
1.300	0.83357	0.00055
1.200	0.83268	0.00054
1.014	0.82385	0.00056
0.900	0.81625	0.00054
0.800	0.80681	0.00051
0.701	0.79379	0.00052
0.601	0.77518	0.00054

Table B-29 Results of MCNP4c2 calculations for 15-wt% U^{235} water/UO_2 slurry in an 8-inch 40ST SS pipe.

U-density g/cc	k_{eff}	σ
2.054	0.98031	0.00059
1.880	0.98693	0.00056
1.700	0.99073	0.00056
1.500	0.99402	0.00054
1.400	0.99478	0.00058
1.300	0.99550	0.00060
1.200	0.99483	0.00057
1.014	0.98535	0.00057
0.900	0.98170	0.00056
0.800	0.97293	0.00056
0.701	0.96056	0.00052
0.601	0.94513	0.00062

Table B-30 Results of MCNP4c2 calculations for 20-wt% U^{235} water/UO_2 slurry in a 6-inch 40ST SS pipe.

U-density g/cc	k_{eff}	σ
2.054	0.85719	0.00055
1.880	0.86064	0.00078
1.700	0.86362	0.00056
1.500	0.86642	0.00055
1.400	0.86778	0.00056
1.300	0.86756	0.00057
1.200	0.86760	0.00053
1.014	0.86208	0.00058
0.900	0.85696	0.00055
0.800	0.85107	0.00057
0.701	0.84075	0.00055
0.601	0.82583	0.00056

Table B-31 Results of MCNP4c2 calculations for 20-wt% U^{235} water/UO_2 slurry in an 8 inch 40ST SS pipe

U-density g/cc	k_{eff}	σ
2.054	1.00855	0.00058
1.880	1.01338	0.00057
1.700	1.01955	0.00057
1.500	1.02474	0.00058
1.400	1.02781	0.00060
1.300	1.02706	0.00057
1.200	1.02934	0.00058
1.014	1.02765	0.00058
0.900	1.02408	0.00056
0.800	1.01778	0.00057
0.701	1.01033	0.00057
0.601	0.99603	0.00055

Table B-32 Results of MCNP4c2 calculations for dry conversion reactor with no moderator

wt% U^{235}	k_{eff}	σ
5	0.68542	0.00081
6	0.71355	0.00088
7	0.73776	0.00084
8	0.75785	0.00090
9	0.77181	0.00090
10	0.78532	0.00087
11	0.79502	0.00087
12	0.80563	0.00083
13	0.81449	0.00090
14	0.82178	0.00089
15	0.82884	0.00090
16	0.83577	0.00102
17	0.84220	0.00100
18	0.84863	0.00098
19	0.85117	0.00093
20	0.85519	0.00092

Table B-33. Results of MCNP4c2 calculations for dry conversion reactor moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.85238	0.00076
6	0.88928	0.00078
7	0.91832	0.00080
8	0.94028	0.00087
9	0.95889	0.00088
10	0.97434	0.00085
11	0.98658	0.00083
12	0.99632	0.00084
13	1.00902	0.00090
14	1.01842	1.01832
15	1.02751	0.00096
16	1.03312	0.00092
17	1.03838	0.00095
18	1.04638	0.00090
19	1.05181	0.00089
20	1.05947	0.00084

Table B-34. Results of MCNP4c2 calculations for dry conversion reactor moderated by 0.8 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.85252	0.00076
6	0.88897	0.00083
7	0.91509	0.00080
8	0.93873	0.00083
9	0.95615	0.00082
10	0.97357	0.00087
11	0.98833	0.00090
12	0.99587	0.00081
13	1.00604	0.00090
14	1.01736	0.00089
15	1.02380	0.00083
16	1.02975	0.00088
17	1.03901	0.00088
18	1.04464	0.00088
19	1.04823	0.00091
20	1.05376	0.00085

Table B-35. Results of MCNP4c2 calculations for dry conversion reactor moderated by 0.5 g/cc water vapor.

wt% U^{235}	k_{eff}	σ
5	0.84681	0.00119
6	0.88206	0.00075
7	0.90967	0.00068
8	0.93218	0.00066
9	0.94990	0.00064
10	0.96790	0.00085
11	0.97958	0.00097
12	0.99034	0.00085
13	0.99956	0.00086
14	1.00941	0.00091
15	1.01640	0.00090
16	1.02311	0.00088
17	1.03164	0.00086
18	1.03727	0.00092
19	1.04317	0.00089
20	1.04831	0.00092

Table B-36. Results of MCNP4c2 calculations for an infinite array of 45 gallon drums containing UO^2 powder moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.74255	0.00072
6	0.77384	0.00069
7	0.80234	0.00074
8	0.82966	0.0007
9	0.84699	0.00073
10	0.86659	0.00073
11	0.88492	0.00071
12	0.90046	0.00075
13	0.91529	0.00076
14	0.92999	0.00077
15	0.94371	0.00074
16	0.95621	0.00073
17	0.96983	0.00073
18	0.98181	0.00072
19	0.99236	0.00073
20	1.00312	0.00069

Table B-37 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.1 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.74625	0.00073
6	0.78026	0.00069
7	0.81145	0.00069
8	0.83766	0.00074
9	0.85854	0.00074
10	0.88131	0.00075
11	0.90181	0.00077
12	0.91858	0.00068
13	0.93651	0.0007
14	0.95289	0.00075
15	0.96817	0.00071
16	0.98263	0.00076
17	0.99535	0.00074
18	1.00863	0.00072
19	1.02286	0.00074
20	1.03416	0.00073

Table B-38 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.2 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.78268	0.00068
6	0.81865	0.00066
7	0.8477	0.0007
8	0.87416	0.00067
9	0.89554	0.00075
10	0.91681	0.0007
11	0.93548	0.0007
12	0.95358	0.00072
13	0.97277	0.0008
14	0.98738	0.00066
15	1.0025	0.00069
16	1.01598	0.00074
17	1.0301	0.0007
18	1.04318	0.00069
19	1.05436	0.00073
20	1.06856	0.0007

Table B-39 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.3 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.79404	0.00071
6	0.82897	0.00074
7	0.85937	0.00073
8	0.88498	0.0007
9	0.90660	0.00074
10	0.92787	0.00077
11	0.94692	0.00072
12	0.96316	0.00066
13	0.97853	0.00072
14	0.99514	0.00072
15	1.01019	0.00071
16	1.02538	0.00072
17	1.0389	0.00074
18	1.04958	0.00076
19	1.0608	0.00067
20	1.07259	0.00074

Table B-40 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.4 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.79046	0.00071
6	0.82324	0.00069
7	0.85398	0.00073
8	0.87963	0.00072
9	0.90207	0.00071
10	0.92289	0.00079
11	0.93692	0.00072
12	0.95733	0.00071
13	0.97426	0.00072
14	0.98938	0.00071
15	1.00293	0.00077
16	1.01537	0.00076
17	1.02872	0.00081
18	1.04312	0.00079
19	1.05313	0.00072
20	1.06486	0.00071

Table B-41 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.5 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.77891	0.00071
6	0.81516	0.00073
7	0.8426	0.00074
8	0.8694	0.00076
9	0.88947	0.0007
10	0.90854	0.00076
11	0.92868	0.00071
12	0.94517	0.00072
13	0.96102	0.00067
14	0.97644	0.00069
15	0.98858	0.00074
16	1.00173	0.00072
17	1.015	0.00075
18	1.02871	0.00072
19	1.03897	0.00072
20	1.0505	0.0007

Table B-42 Results of MCNP4c2 calculations for an infinite array of 45-gallon drums containing UO^2 powder moderated by 0.8 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.75257	0.00071
6	0.78888	0.00075
7	0.81321	0.00068
8	0.83978	0.00073
9	0.85881	0.00068
10	0.87947	0.00072
11	0.89817	0.00071
12	0.91313	0.00072
13	0.92763	0.00073
14	0.94402	0.00073
15	0.95542	0.00073
16	0.96989	0.00071
17	0.98081	0.00069
18	0.99298	0.00065
19	1.00586	0.00081
20	1.01888	0.00079

Table B-43 Results of MCNP4c2 calculations for single molybdenum pellet boat containing completely packed UO^2 pellets moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.49688	0.00062
6	0.51483	0.00060
7	0.52962	0.00064
8	0.54493	0.00063
9	0.55530	0.00066
10	0.56732	0.00065
11	0.57874	0.00066
12	0.58901	0.00064
13	0.59970	0.00069
14	0.60789	0.00066
15	0.61685	0.00067
16	0.62655	0.00068
17	0.63412	0.00069
18	0.64176	0.00070
19	0.65059	0.00071
20	0.65777	0.00070

Table B-44 Results of MCNP4c2 calculations for single molybdenum pellet boat containing a 2 to 1 ratio by volume of water to UO^2 moderated by water at 20 °C.

wt% U^{235}	k_{eff}	σ
5	0.64938	0.00078
6	0.67035	0.00072
7	0.69857	0.00080
8	0.70180	0.00083
9	0.71256	0.00086
10	0.72322	0.00078
11	0.73285	0.00080
12	0.74005	0.00078
13	0.74882	0.00090
14	0.75314	0.00086
15	0.76123	0.00077
16	0.76498	0.00082
17	0.77118	0.00079
18	0.77572	0.00080
19	0.77802	0.00084
20	0.78635	0.00084

Table B-45 Results of MCNP4c2 calculations for infinite array of molybdenum pellet boats containing a 2 to 1 ratio by volume of water to UO^2 moderated by 0.05 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.66036	0.00082
6	0.68183	0.00079
7	0.70087	0.00079
8	0.71630	0.00078
9	0.72870	0.00084
10	0.73712	0.00074
11	0.74922	0.00082
12	0.75776	0.00080
13	0.76431	0.00083
14	0.76887	0.00085
15	0.77699	0.00083
16	0.78436	0.00080
17	0.78838	0.00082
18	0.79249	0.00078
19	0.79977	0.00083
20	0.80561	0.00083

Table B-46 Results of MCNP4c2 calculations for infinite array of molybdenum pellet boats containing a 2 to 1 ratio by volume of water to UO^2 moderated by 0.1 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.82140	0.00073
6	0.85199	0.00072
7	0.87684	0.00078
8	0.89509	0.00077
9	0.91077	0.00074
10	0.92587	0.00076
11	0.93682	0.00070
12	0.94538	0.00075
13	0.95794	0.00074
14	0.96788	0.00075
15	0.97507	0.00077
16	0.98157	0.00077
17	0.98869	0.00079
18	0.99632	0.00083
19	1.00229	0.00081
20	1.00839	0.00079

Table B-47 Results of MCNP4c2 calculations for infinite array of molybdenum pellet boats containing a 2 to 1 ratio by volume of water to UO^2 moderated by 0.2 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.70063	0.00067
6	0.72598	0.00077
7	0.74471	0.00075
8	0.75778	0.00076
9	0.77387	0.00078
10	0.78296	0.00086
11	0.79490	0.00076
12	0.80208	0.00083
13	0.81113	0.00085
14	0.81886	0.00078
15	0.82549	0.00085
16	0.83132	0.00074
17	0.83700	0.00083
18	0.84218	0.00083
19	0.84732	0.00082
20	0.85180	0.00081

Table B-48 Results of MCNP5 mpi calculations for single 15x15 assembly moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.94609	0.00065
6	0.97178	0.00068
7	0.98230	0.00069
8	1.00645	0.00074
9	1.01840	0.00071
10	1.03078	0.00071
11	1.03810	0.00071
12	1.04840	0.00071
13	1.05417	0.00069
14	1.06078	0.00076
15	1.06523	0.00074
16	1.07016	0.00074
17	1.07714	0.00070
18	1.08182	0.00067
19	1.08556	0.00071
20	1.08981	0.00075

Table B-49. Results of MCNP5 mpi calculations for single 15x15 assembly with steel rod inserts moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.90837	0.00070
6	0.93384	0.00067
7	0.95319	0.00069
8	0.96937	0.00068
9	0.98396	0.00070
10	0.99519	0.00069
11	1.00459	0.00071
12	1.01286	0.00068
13	1.02027	0.00070
14	1.02605	0.00072
15	1.03286	0.00072
16	1.04019	0.00071
17	1.04478	0.00072
18	1.05107	0.00069
19	1.05610	0.00080
20	1.06099	0.00077

Table B-50. Results of MCNP5 mpi calculations for single 15x15 assembly with a BPRA moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.81935	0.00068
6	0.84909	0.00070
7	0.87179	0.00072
8	0.89155	0.00072
9	0.90841	0.00071
10	0.92120	0.00068
11	0.93303	0.00071
12	0.94501	0.00071
13	0.95353	0.00068
14	0.96343	0.00073
15	0.97002	0.00072
16	0.97731	0.00070
17	0.98331	0.00072
18	0.99134	0.00072
19	0.99597	0.00075
20	1.00154	0.00069

Table B-51 Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.92146	0.00067
6	0.94689	0.00071
7	0.96614	0.00070
8	0.98314	0.00071
9	0.99766	0.00067
10	1.00544	0.00069
11	1.01802	0.00076
12	1.02753	0.00074
13	1.03328	0.00076
14	1.04183	0.00071
15	1.04539	0.00066
16	1.05439	0.00075
17	1.05964	0.00072
18	1.06471	0.00076
19	1.07066	0.00070
20	1.07478	0.00074

Table B-52 Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by 0.9 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.88256	0.00067
6	0.90658	0.00071
7	0.92616	0.00066
8	0.94294	0.00064
9	0.95527	0.00068
10	0.96746	0.00072
11	0.97729	0.00068
12	0.98586	0.00072
13	0.99256	0.00073
14	1.00076	0.00073
15	1.00744	0.00068
16	1.01294	0.00069
17	1.01865	0.00072
18	1.02420	0.00070
19	1.02945	0.00074
20	1.03406	0.00071

Table B-53 Results of MCNP5.mpi calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by 0.8 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.83969	0.00080
6	0.86378	0.00069
7	0.88264	0.00068
8	0.89737	0.00068
9	0.91114	0.00074
10	0.92124	0.00067
11	0.93231	0.00074
12	0.93964	0.00074
13	0.94652	0.00078
14	0.95527	0.00069
15	0.96021	0.00071
16	0.96844	0.00072
17	0.97450	0.00077
18	0.97875	0.00063
19	0.98363	0.00074
20	0.98947	0.00073

Table B-54. Results of MCNP5.mpi calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by 0.7 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.79215	0.00067
6	0.81405	0.00073
7	0.83120	0.00071
8	0.84674	0.00069
9	0.85938	0.00063
10	0.87038	0.00067
11	0.87969	0.00068
12	0.88983	0.00071
13	0.89847	0.00070
14	0.90655	0.00068
15	0.91109	0.00070
16	0.91918	0.00065
17	0.92402	0.00074
18	0.92903	0.00078
19	0.93481	0.00071
20	0.94072	0.00072

Table B-55 Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by 0.5 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.67812	0.00062
6	0.70097	0.00063
7	0.71804	0.00064
8	0.73326	0.00062
9	0.74590	0.00067
10	0.75701	0.00066
11	0.76709	0.00068
12	0.77578	0.00073
13	0.78607	0.00069
14	0.79265	0.00064
15	0.80068	0.00065
16	0.80656	0.00068
17	0.81563	0.00068
18	0.82187	0.00071
19	0.82670	0.00075
20	0.83292	0.00068

Table B-56 Results of MCNP5.mpl calculations for infinite array of shipping containers containing two 15x15 assemblies moderated by 0.3 g/cc water vapor

wt% U^{235}	k_{eff}	σ
5	0.54433	0.00058
6	0.56468	0.00056
7	0.58005	0.00061
8	0.59513	0.00059
9	0.60774	0.00059
10	0.61815	0.00060
11	0.63005	0.00064
12	0.63928	0.00060
13	0.64887	0.00068
14	0.65760	0.00064
15	0.66577	0.00062
16	0.67361	0.00065
17	0.68152	0.00066
18	0.68827	0.00067
19	0.69476	0.00059
20	0.70216	0.00068

Table B-57 Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies with no moderator

wt% U^{235}	k_{eff}	σ
5	0.11534	0.00011
6	0.12007	0.00012
7	0.12495	0.00011
8	0.12979	0.00011
9	0.13465	0.00012
10	0.13958	0.00012
11	0.14414	0.00013
12	0.14964	0.00011
13	0.15380	0.00012
14	0.15847	0.00013
15	0.16301	0.00013
16	0.16784	0.00013
17	0.17241	0.00014
18	0.17692	0.00014
19	0.18172	0.00014
20	0.18599	0.00014

Table B-58 Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies with steel inserts moderated by water at 20 °C

wt% U^{235}	k_{eff}	σ
5	0.87962	0.00066
6	0.90656	0.00063
7	0.92775	0.00065
8	0.94585	0.00070
9	0.95831	0.00069
10	0.97106	0.00074
11	0.98106	0.00076
12	0.99183	0.00073
13	1.00062	0.00068
14	1.00825	0.00073
15	1.01404	0.00075
16	1.02124	0.00068
17	1.02685	0.00071
18	1.03271	0.00073
19	1.03705	0.00070
20	1.04423	0.00072

Table B-59. Results of MCNP5 mpi calculations for infinite array of shipping containers containing two 15x15 assemblies with BPRAs moderated by water at 20 °C.

wt% U^{235}	k_{eff}	σ
5	0.78896	0.00066
6	0.82077	0.00066
7	0.84519	0.00068
8	0.86486	0.00074
9	0.88050	0.00070
10	0.89539	0.00073
11	0.90979	0.00064
12	0.92097	0.00071
13	0.93095	0.00072
14	0.93923	0.00072
15	0.94869	0.00068
16	0.95673	0.00071
17	0.96361	0.00076
18	0.96913	0.00073
19	0.97617	0.00071
20	0.98366	0.00073

Table B-60. Results of MCNP5 mpi calculations a spent fuel pool containing no boron

wt% U^{235}	k_{eff}	σ
5	0.93986	0.00064
6	0.96320	0.00067
7	0.98441	0.00069
8	1.00030	0.00069
9	1.01329	0.00066
10	1.02529	0.00078
11	1.03476	0.00068
12	1.04352	0.00078
13	1.05119	0.00069
14	1.05771	0.00073
15	1.06336	0.00074
16	1.06961	0.00070
17	1.07466	0.00078
18	1.07953	0.00074
19	1.08437	0.00075
20	1.08825	0.00072

Table B-61 Results of MCNP5 mpi calculations a spent fuel pool containing 500-ppm boron.

wt% U^{235}	k_{eff}	σ
5	0.85571	0.00066
6	0.88282	0.00070
7	0.90662	0.00070
8	0.92558	0.00067
9	0.94090	0.00077
10	0.95427	0.00069
11	0.96471	0.00074
12	0.97565	0.00078
13	0.98311	0.00075
14	0.99280	0.00071
15	1.00025	0.00075
16	1.00751	0.00071
17	1.01218	0.00077
18	1.01864	0.00074
19	1.02443	0.00078
20	1.03122	0.00073

Table B-62 Results of MCNP5.mpi calculations a spent fuel pool using BPRA's and containing no boron.

wt% U^{235}	k_{eff}	σ
5	0.80844	0.00069
6	0.83958	0.00069
7	0.86250	0.00068
8	0.88263	0.00069
9	0.89886	0.00072
10	0.91513	0.00074
11	0.92646	0.00069
12	0.93799	0.00070
13	0.94849	0.00069
14	0.95922	0.00076
15	0.96627	0.00072
16	0.97453	0.00074
17	0.98161	0.00068
18	0.98820	0.00073
19	0.99432	0.00074
20	0.99981	0.00075

Table B-63 Results of MCNP5.mpi calculations a spent fuel pool using BPRA's and containing 500 ppm boron.

wt% U^{235}	k_{eff}	σ
5	0.73898	0.00070
6	0.77120	0.00063
7	0.79763	0.00073
8	0.81828	0.00069
9	0.83675	0.00068
10	0.85244	0.00072
11	0.86646	0.00068
12	0.87626	0.00066
13	0.88932	0.00067
14	0.90108	0.00073
15	0.90927	0.00069
16	0.91826	0.00067
17	0.92687	0.00074
18	0.93328	0.00070
19	0.94092	0.00074
20	0.94808	0.00074

APPENDIX C
CASMO-3 INPUT FILES

This appendix contains the base case CASMO-3 input file used to determine discharge burnups and cycle lengths for enrichments from 5-wt% U^{235} to 10-wt% U^{235}

TheCASMO-3 Input File Single 17x17 Assembly with 5-wt% U^{235} Fuel

```
TTL  FU=535 THO-583 IDE="NEXZ"  * Westinghouse 17x17
*

BOR 0

FUE 1 10 4/5 0

PWR 17 1 26

SPA 14 96  16 E 6   7 96/718=100 *  Inconel-718 grid


PIN 1  4095  416  475/  5   AIR   CAN  *Fuel Gap Zirc
PIN 2  5715  61214   /  MOD   BOX     * Control Rod Tube
PIN 3  5715  61214   /  MOD   BOX     * Instrument Tube


LPI
3
1 1
1 1 1
2 1 1 2
1 1 1 1 1
1 1 1 1 1 2
2 1 1 2 1 1 1
1 1 1 1 1 1 1 1
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POC 37 67


DEP  120


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APPENDIX D
CASMO-3 AND CASFIND-6 CALCULATION RESULTS

This appendix contains the results from CASMO-3 and CASFIND-6 calculations for discharge burnups and cycle lengths for enrichments from 5-wt% U^{235} to 10-wt% U^{235}

Table D-1. Results of CASMO-3 and CASFIND-6 calculations of the number of batches for 15-day outage plants

Enrichment wt% U^{235}	12-month Batches In Core	18-month Batches In Core	24-month Batches In Core	30-month Batches In Core	36-month Batches In Core	42-month Batches In Core
4.5	4.71	2.73	1.77	1.15	n/a	n/a
5.0	5.35	3.08	2.00	1.44	n/a	n/a
5.5	5.94	3.55	2.36	1.65	1.18	n/a
6.0	6.60	3.93	2.67	1.88	1.42	n/a
6.5	7.18	4.37	2.93	2.11	1.63	1.20
7.0	7.76	4.75	3.25	2.38	1.80	1.40
7.5	8.33	5.09	3.57	2.63	1.95	1.58
8.0	9.00	5.54	3.83	2.83	2.15	1.73
8.5	9.55	5.88	4.10	3.02	2.37	1.88
9.0	10.08	6.27	4.40	3.28	2.58	1.97
9.5	10.70	6.65	4.67	3.52	2.74	2.15
10.0	11.30	7.00	4.93	3.73	2.89	2.34

Table D-2 Results of CASMO-3 and CASFIND 6 calculations of the number of batches for 30-day outage plants.

Enrichment wt% U^{235}	12-month Batches In Core	18-month Batches In Core	24-month Batches In Core	30-month Batches In Core	36-month Batches In Core	42-month Batches In Core
4.5	4.95	2.82	1.82	1.20	n/a	n/a
5.0	5.65	3.24	2.08	1.48	n/a	n/a
5.5	6.22	3.68	2.44	1.72	1.22	n/a
6.0	6.93	4.07	2.75	1.92	1.46	n/a
6.5	7.50	4.53	3.00	2.18	1.66	1.24
7.0	8.14	4.81	3.35	2.45	1.83	1.43
7.5	8.67	5.23	3.67	2.68	1.98	1.61
8.0	9.42	5.73	3.93	2.89	2.20	1.75
8.5	10.00	6.10	4.23	3.11	2.42	1.88
9.0	10.60	6.50	4.53	3.36	2.61	2.00
9.5	11.20	6.87	4.79	3.56	2.78	2.20
10.0	11.80	7.26	5.08	3.80	2.94	2.39

Table D-3 Results of CASMO-3 and CASFIND-6 calculations of burnup in 15-day outage plants.

Enrichment wt% U^{235}	12-month Discharge Burnup GWd/mtU	18-month Discharge Burnup GWd/mtU	24 month Discharge Burnup GWd/mtU	30-month Discharge Burnup GWd/mtU	36-month Discharge Burnup GWd/mtU	42 month Discharge Burnup GWd/mtU
4.5	60.65	52.71	44.85	37.00	n/a	n/a
5.0	68.95	60.68	53.04	45.12	n/a	n/a
5.5	77.17	69.17	61.16	53.20	45.31	n/a
6.0	85.35	77.32	69.32	61.37	53.61	n/a
6.5	93.46	85.42	77.37	69.47	61.58	53.70
7.0	101.25	93.28	85.31	77.39	69.46	61.60
7.5	109.05	101.05	93.16	85.24	77.32	69.44
8.0	116.72	108.73	100.82	92.88	84.95	77.10
8.5	124.16	116.27	108.39	100.45	92.52	84.65
9.0	131.68	123.73	115.82	107.63	100.04	92.13
9.5	139.14	131.16	123.25	115.39	107.52	99.60
10.0	146.72	138.65	130.74	122.81	114.87	107.02

Table D-4 Results of CASMO-3 and CASFIND-6 calculations of burnup in 30-day outage plants

Enrichment wt% U^{235}	12 month Discharge Burnup GWd/mtU	18-month Discharge Burnup GWd/mtU	24-month Discharge Burnup GWd/mtU	30-month Discharge Burnup GWd/mtU	36-month Discharge Burnup GWd/mtU	42-month Discharge Burnup GWd/mtU
4.5	61.31	53.37	45.51	37.66	n/a	n/a
5.0	69.61	61.56	53.69	45.79	n/a	n/a
5.5	77.85	69.63	61.62	53.86	45.98	n/a
6.0	86.03	77.39	69.88	62.03	54.16	n/a
6.5	94.14	86.09	78.03	70.13	62.24	54.36
7.0	101.91	93.96	85.97	78.05	70.15	62.26
7.5	109.71	101.71	93.84	85.91	77.98	70.09
8.0	117.42	109.40	101.48	93.54	85.61	77.78
8.5	124.83	116.93	109.04	101.11	93.18	85.30
9.0	132.29	124.40	116.49	108.58	100.70	92.78
9.5	139.81	131.86	123.91	116.04	108.18	100.26
10.0	147.42	139.32	131.40	123.49	115.53	107.88

APPENDIX E
FUEL CYCLE COST CALCULATIONS

This appendix contains tables of all of the fuel cycle cost calculations

Table E-1. Base fuel cycle costs for 15-day outage plants for the first 5 years.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18 month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.43	7.85	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.48	7.77	7.70	8.01	8.82	n/a
6.0	8.55	7.78	7.63	7.81	8.31	n/a
6.5	8.61	7.80	7.59	7.70	8.09	8.63
7.0	8.72	7.87	7.63	7.70	7.98	8.44
7.5	8.81	7.92	7.68	7.69	7.84	8.28
8.0	8.93	8.03	7.72	7.68	7.83	8.16
8.5	9.05	8.12	7.79	7.71	7.86	8.08
9.0	9.17	8.23	7.89	7.80	7.88	8.01
9.5	9.31	8.35	7.88	7.89	7.93	8.05
10.0	9.45	8.46	8.07	7.96	7.96	8.12

Table E-2. Base fuel cycle costs for 30-day outage plants for the first 5 years.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.24	9.35	9.34	9.99	n/a	n/a
5.0	9.27	9.29	9.12	8.51	n/a	n/a
5.5	9.31	9.26	9.07	8.27	9.80	n/a
6.0	9.38	9.29	9.01	8.07	9.50	n/a
6.5	9.44	9.28	7.99	7.99	9.30	8.79
7.0	9.58	9.41	9.03	8.00	9.17	8.91
7.5	9.64	9.47	9.07	7.99	9.06	8.45
8.0	9.79	9.59	9.12	7.99	9.06	8.34
8.5	9.91	9.68	9.21	9.03	9.11	9.29
9.0	10.02	9.80	9.30	9.12	9.14	9.20
9.5	10.19	9.91	9.39	9.20	9.17	9.27
10.0	10.32	9.04	9.49	9.28	9.20	9.33

Table E-3 Base fuel cycle costs for 15-day outage plants after the first 5 years

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
8.4	8.43	7.85	8.01	8.87	n/a	n/a
8.4	8.44	7.77	7.77	8.27	n/a	n/a
8.5	8.48	7.75	7.68	8.00	8.81	n/a
8.5	8.54	7.74	7.62	7.80	8.30	n/a
8.6	8.60	7.78	7.58	7.69	8.08	8.62
8.7	8.71	7.84	7.60	7.58	7.88	8.43
8.8	8.80	7.88	7.65	7.58	7.83	8.27
8.9	8.92	8.00	7.69	7.68	7.82	8.18
9.0	9.04	8.09	7.76	7.70	7.85	8.07
9.2	9.15	8.20	7.86	7.79	7.88	8.00
9.3	9.30	8.32	7.95	7.87	7.81	8.04
9.4	9.44	8.43	8.04	7.95	7.94	8.10

Table E-4 Base fuel cycle costs for 30-day outage plants after the first 5 years.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
9.4	9.40	8.51	8.50	9.08	n/a	n/a
9.4	9.45	8.47	8.29	8.70	n/a	n/a
9.5	9.50	8.48	8.28	8.48	9.00	n/a
9.6	9.60	8.50	8.21	8.28	8.72	n/a
9.7	9.68	8.58	8.19	8.22	8.83	9.02
9.8	9.83	8.67	8.23	8.25	8.43	8.87
9.9	9.94	8.75	8.36	8.27	8.33	8.74
10.1	10.12	8.81	8.42	8.29	8.37	8.64
10.3	10.27	9.03	8.54	8.38	8.44	8.58
10.4	10.42	9.16	8.87	8.48	8.50	8.52
10.6	10.62	9.33	8.79	8.60	8.55	8.64
10.8	10.80	9.50	8.92	8.70	8.60	8.74

Table E-5. Fuel cycle costs for plants with 15-day outage for the first 5 years with 15 participating reactors.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.43	7.85	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.48	7.76	7.70	8.01	8.61	n/a
6.0	8.54	7.76	7.63	7.81	8.30	n/a
6.5	8.61	7.80	7.59	7.70	8.09	8.63
7.0	8.72	7.87	7.63	7.70	7.96	8.44
7.5	8.80	7.82	7.66	7.59	7.84	8.27
8.0	8.93	8.03	7.72	7.88	7.82	8.18
8.5	9.05	8.12	7.79	7.71	7.86	8.07
9.0	9.18	8.23	7.89	7.80	7.88	8.01
9.5	9.31	8.35	7.98	7.88	7.92	8.08
10.0	9.45	8.45	8.07	7.96	7.95	8.11

Table E-6 Fuel cycle costs for plants with 30-day outage for the first 5 years with 15 participating reactors

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.24	8.35	8.34	8.69	n/a	n/a
5.0	8.27	8.28	8.12	8.51	n/a	n/a
5.5	8.31	8.29	8.06	8.27	8.78	n/a
6.0	8.38	8.29	8.00	8.07	8.50	n/a
6.5	8.44	8.34	7.96	7.96	8.30	8.78
7.0	8.56	8.41	8.03	8.00	8.17	8.60
7.5	8.64	8.46	8.07	7.99	8.06	8.45
8.0	8.78	8.59	8.12	7.99	8.07	8.34
8.5	8.91	8.68	8.20	8.03	8.11	8.28
9.0	10.02	8.80	8.30	8.12	8.14	8.20
9.5	10.18	8.91	8.39	8.20	8.17	8.27
10.0	10.32	9.04	8.49	8.27	8.20	8.33

Table E-7. Fuel cycle costs for plants with 15-day outage for the first 5 years with 20 participating reactors

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.43	7.85	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.48	7.78	7.70	8.01	8.61	n/a
6.0	8.54	7.76	7.83	7.81	8.30	n/a
6.5	8.61	7.80	7.56	7.69	8.09	8.63
7.0	8.72	7.87	7.63	7.70	7.96	8.43
7.5	8.80	7.92	7.68	7.69	7.84	8.27
8.0	8.93	8.03	7.72	7.66	7.82	8.18
8.5	9.05	8.12	7.79	7.71	7.86	8.07
9.0	9.18	8.23	7.89	7.80	7.89	8.01
9.5	9.30	8.35	7.96	7.68	7.92	8.05
10.0	9.45	8.45	8.07	7.96	7.95	8.11

Table E-8 Fuel cycle costs for plants with 30-day outage for the first 5 years with 20 participating reactors.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.24	8.35	8.34	8.89	n/a	n/a
5.0	8.27	8.29	8.12	8.51	n/a	n/a
5.5	8.31	8.26	8.06	8.26	8.79	n/a
6.0	8.38	8.29	8.00	8.07	8.50	n/a
6.5	8.44	8.34	7.96	7.99	8.28	8.78
7.0	8.56	8.41	8.03	7.99	8.17	8.60
7.5	8.64	8.48	8.07	7.99	8.08	8.45
8.0	8.78	8.58	8.11	7.99	8.07	8.34
8.5	9.90	8.68	8.20	8.03	8.11	8.26
9.0	10.02	8.80	8.30	8.12	8.14	8.20
9.5	10.17	8.91	8.39	8.20	8.17	8.27
10.0	10.31	8.04	8.48	8.27	8.20	8.33

Table E-9 Fuel cycle costs for plants with 15-day outage for the first 5 years with 25 participating reactors.

Enrichment wt% U^{235}	12 month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.43	7.85	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.48	7.76	7.70	8.01	8.61	n/a
6.0	8.54	7.75	7.63	7.81	8.30	n/a
6.5	8.61	7.80	7.58	7.69	8.09	8.63
7.0	8.72	7.87	7.63	7.70	7.96	8.43
7.5	8.60	7.92	7.68	7.69	7.84	8.27
8.0	8.23	8.03	7.72	7.69	7.82	8.18
8.5	8.04	8.12	7.78	7.70	7.86	8.07
9.0	8.18	8.23	7.89	7.80	7.86	8.01
9.5	8.30	8.34	7.88	7.86	7.92	8.05
10.0	8.45	8.45	8.07	7.96	7.95	8.11

Table E-10. Fuel cycle costs for plants with 30-day outage for the first 5 years with 25 participating reactors.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24 month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.24	8.35	8.34	8.89	n/a	n/a
5.0	8.27	8.28	8.12	8.51	n/a	n/a
5.5	8.30	8.29	8.06	8.28	8.79	n/a
6.0	8.38	8.29	8.00	8.07	8.50	n/a
6.5	9.44	8.34	7.96	7.99	8.28	8.78
7.0	8.56	8.41	8.03	7.98	8.17	8.60
7.5	8.64	8.46	8.07	7.93	8.06	8.45
8.0	8.78	8.59	8.11	7.96	8.07	8.34
8.5	9.90	8.68	8.20	8.03	8.11	8.26
9.0	10.01	8.80	8.30	8.12	8.14	8.19
9.5	10.17	8.91	8.39	8.20	8.17	8.28
10.0	10.31	9.04	8.49	8.27	8.20	8.33

Table E-11 Fuel cycle costs for plants with 15-day outage for the first 5 years with 5 participating reactors

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18 month Fuel Cycle Cost mills/kWhr$_e$	24 month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.43	7.88	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.48	7.77	7.70	8.02	8.62	n/a
6.0	8.55	7.78	7.64	7.82	8.31	n/a
6.5	8.62	7.81	7.60	7.70	8.10	8.63
7.0	8.73	7.88	7.64	7.71	7.97	8.44
7.5	8.81	7.93	7.69	7.70	7.85	8.28
8.0	8.94	8.04	7.73	7.70	7.83	8.17
8.5	9.06	8.14	7.80	7.72	7.87	8.09
9.0	9.18	8.28	7.90	7.81	7.91	8.02
9.5	9.32	8.36	8.00	7.90	7.94	8.06
10.0	9.47	8.47	8.06	7.87	7.87	8.13

Table E-12. Fuel cycle costs for plants with 30-day outage for the first 5 years with 5 participating reactors

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.24	8.35	8.34	8.69	n/a	n/a
5.0	9.27	8.28	8.12	8.51	n/a	n/a
5.5	9.31	8.30	8.07	8.27	8.80	n/a
6.0	9.39	8.30	8.01	8.08	8.51	n/a
6.5	9.45	8.35	7.97	8.00	8.30	8.79
7.0	9.57	8.42	8.04	8.00	8.18	8.61
7.5	9.65	8.47	8.08	8.00	8.07	8.46
8.0	9.78	8.60	8.12	8.00	8.08	8.35
8.5	9.92	8.70	8.22	8.08	8.12	8.27
9.0	10.03	8.82	8.32	8.14	8.16	8.21
9.5	10.18	8.93	8.41	8.22	8.19	8.28
10.0	10.33	9.06	8.50	8.29	8.22	8.35

Table E-13. Fuel cycle costs for plants with 15-day outage for the first 5 years with 2 participating reactors

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.3	8.43	7.85	8.01	8.67	n/a	n/a
5.0	8.44	7.77	7.77	8.27	n/a	n/a
5.5	8.52	7.81	7.74	8.05	8.65	n/a
6.0	8.59	7.80	7.87	7.85	8.35	n/a
6.5	8.65	7.84	7.63	7.74	8.13	8.67
7.0	8.78	7.92	7.68	7.74	8.00	8.48
7.5	8.85	7.97	7.72	7.74	7.88	8.32
8.0	8.98	8.06	7.77	7.74	7.87	8.20
8.5	9.14	8.21	7.88	7.80	7.95	8.16
9.0	9.28	8.33	7.98	7.89	7.98	8.09
9.5	9.41	8.45	8.08	7.98	8.02	8.14
10.0	9.55	8.56	8.17	8.06	8.05	8.21

Table E-14 Fuel cycle costs for plants with 30-day outage for the first 5 years with 2 participating reactors

Enrichment wt% U^{235}	12 month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36 month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.24	8.35	8.34	8.69	n/a	n/a
5.0	8.27	8.28	8.12	8.51	n/a	n/a
5.5	8.35	8.33	8.11	8.31	8.84	n/a
6.0	8.42	8.33	8.05	8.11	8.54	n/a
6.5	8.49	8.39	8.01	8.03	8.34	8.63
7.0	9.60	8.46	8.07	8.04	8.22	8.65
7.5	9.69	8.51	8.12	8.03	8.10	8.48
8.0	9.83	8.63	8.18	8.04	8.12	8.38
8.5	10.01	8.78	8.30	8.12	8.20	8.35
9.0	10.12	8.90	8.40	8.21	8.23	8.28
9.5	10.28	9.01	8.49	8.30	8.27	8.36
10.0	10.42	9.15	8.58	8.37	8.30	8.43

Table E-15 Fuel cycle costs for plants with 15-day outage for the first 5 years with 1 participating reactor

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.43	7.95	9.01	9.67	n/a	n/a
5.0	9.44	7.77	7.77	9.27	n/a	n/a
5.5	9.63	7.81	7.84	9.19	8.75	n/a
6.0	8.69	7.90	7.78	7.95	9.45	n/a
6.5	9.76	7.99	7.73	7.84	8.24	8.77
7.0	9.87	8.02	7.79	7.88	9.11	8.88
7.5	9.96	8.09	7.83	7.86	7.99	9.43
8.0	9.10	8.19	7.88	7.65	7.88	9.31
8.5	9.41	8.47	8.13	8.04	9.19	9.40
9.0	9.54	8.59	9.24	9.18	8.24	9.33
9.5	9.69	9.72	8.35	8.24	9.27	9.39
10.0	9.85	8.93	9.44	9.32	8.31	9.47

Table E-16 Fuel cycle costs for plants with 30-day outage for the first 5 years with 1 participating reactor

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.24	8.35	8.34	8.89	n/a	n/a
5.0	9.27	8.29	8.12	8.61	n/a	n/a
5.5	9.48	8.43	8.21	8.41	8.63	n/a
6.0	9.53	8.44	8.15	8.21	8.65	n/a
6.5	9.60	8.50	8.11	8.14	8.44	8.93
7.0	9.72	8.57	8.18	8.15	8.32	8.75
7.5	9.80	8.62	8.23	8.14	8.21	8.60
8.0	9.95	8.79	8.27	8.15	8.23	8.49
8.5	10.26	9.04	8.56	8.37	8.45	8.58
9.0	10.39	9.17	8.68	8.47	8.49	8.52
9.5	10.57	9.29	8.76	8.56	8.52	8.61
10.0	10.72	9.43	8.86	8.64	8.56	8.69

Table E-17. Fuel cycle costs for plants with 15-day outage for the first 5 years with ore costs increased to $60 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.65	8.44	8.70	9.48	n/a	n/a
5.0	8.96	8.35	8.43	9.03	n/a	n/a
5.5	9.01	8.35	8.34	8.74	9.45	n/a
6.0	9.08	8.34	8.27	8.52	9.11	n/a
6.5	9.15	8.39	8.23	8.39	8.88	9.50
7.0	9.26	8.47	8.27	8.40	8.72	9.26
7.5	9.38	8.53	8.33	8.39	8.59	9.10
8.0	9.52	8.65	8.36	8.39	8.57	8.57
8.5	9.65	8.76	8.45	8.41	8.61	8.87
9.0	9.78	8.88	8.57	8.51	8.65	8.80
9.5	9.95	9.01	8.67	8.61	8.68	8.85
10.0	10.11	9.13	8.77	8.69	8.72	8.92

Table E-18 Fuel cycle costs for plants with 30-day outage for the first 5 years with ore costs increased to $60 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.74	8.92	9.00	9.67	n/a	n/a
5.0	9.77	8.85	8.75	9.25	n/a	n/a
5.5	9.81	8.85	8.70	8.96	9.62	n/a
6.0	9.90	8.88	8.63	8.77	9.29	n/a
6.5	9.97	8.92	8.58	8.68	9.06	9.64
7.0	10.10	9.00	8.66	8.68	8.92	9.43
7.5	10.19	9.06	8.71	8.67	8.79	9.28
8.0	10.36	9.20	8.76	8.68	8.81	9.14
8.5	10.50	9.30	8.86	8.72	8.85	9.05
9.0	10.62	9.44	8.97	8.83	8.86	8.96
9.5	10.80	9.56	9.07	8.92	8.92	9.06
10.0	10.96	9.71	9.18	9.00	8.96	9.13

Table E-19 Fuel cycle costs for plants with 15-day outage for the first 5 years with ore costs increased to $80 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.47	9.03	9.39	10.29	n/a	n/a
5.0	9.49	8.93	9.08	9.80	n/a	n/a
5.5	9.54	8.93	8.99	9.49	10.29	n/a
6.0	9.62	8.92	8.91	9.23	9.91	n/a
6.5	9.70	8.99	8.86	9.09	9.64	10.36
7.0	9.84	9.07	8.92	9.09	9.47	10.12
7.5	9.95	9.14	8.99	9.08	9.33	9.92
8.0	10.11	9.29	9.03	9.09	9.31	9.78
8.5	10.26	9.39	9.12	9.11	9.36	9.67
9.0	10.40	9.53	9.25	9.22	9.40	9.59
9.5	10.59	9.68	9.37	9.33	9.44	9.64
10.0	10.79	9.91	9.45	9.43	9.48	9.73

Table E-20 Fuel cycle costs for plants with 30-day outage for the first 5 years with ore costs increased to $80 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	10.23	9.48	9.66	10.45	n/a	n/a
5.0	10.27	9.42	9.39	9.89	n/a	n/a
5.5	10.32	9.42	9.33	9.69	10.43	n/a
6.0	10.41	9.43	9.26	9.46	10.07	n/a
6.5	10.50	9.50	9.21	9.36	9.82	10.49
7.0	10.64	9.58	9.29	9.36	9.66	10.26
7.5	10.75	9.65	9.35	9.36	9.52	10.07
8.0	10.93	9.80	9.40	9.36	9.54	9.93
8.5	11.08	9.92	9.52	9.41	9.59	9.83
9.0	11.22	10.08	9.64	9.53	9.63	9.76
9.5	11.42	10.22	9.76	9.63	9.67	9.85
10.0	11.60	10.38	9.87	9.72	9.71	9.93

Table E-21 Fuel cycle costs for plants with 15-day outage for the first 5 years with ore costs decreased to $20 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	7.82	7.27	7.33	7.67	n/a	n/a
5.0	7.82	7.19	7.12	7.51	n/a	n/a
5.5	7.86	7.18	7.05	7.28	7.76	n/a
6.0	8.01	7.17	6.99	7.10	7.50	n/a
6.5	8.06	7.21	6.95	7.00	7.31	7.76
7.0	8.16	7.27	6.98	7.01	7.20	7.60
7.5	8.23	7.32	7.03	7.00	7.10	7.45
8.0	8.34	7.41	7.07	7.00	7.08	7.35
8.5	8.45	7.49	7.13	7.01	7.11	7.28
9.0	8.55	7.58	7.21	7.09	7.14	7.22
9.5	8.67	7.69	7.29	7.16	7.17	7.26
10.0	8.80	7.78	7.37	7.23	7.19	7.31

Table E-22 Fuel cycle costs for plants with 30-day outage for the first 5 years with ore costs decreased to $20 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.76	7.79	7.68	8.10	n/a	n/a
5.0	8.77	7.73	7.46	7.77	n/a	n/a
5.5	8.80	7.73	7.44	7.55	7.98	n/a
6.0	8.86	7.72	7.38	7.38	7.72	n/a
6.5	8.92	7.77	7.34	7.31	7.54	7.93
7.0	9.02	7.83	7.40	7.32	7.43	7.79
7.5	9.09	7.87	7.44	7.31	7.33	7.64
8.0	9.21	7.98	7.48	7.31	7.34	7.56
8.5	9.32	8.06	7.56	7.35	7.37	7.48
9.0	9.42	8.17	7.64	7.42	7.40	7.42
9.5	9.56	8.28	7.71	7.49	7.43	7.48
10.0	9.66	8.38	7.80	7.55	7.46	7.54

Table E-23. Fuel cycle costs for plants with 15-day outage for the first 5 years with conversion costs increased to $10 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.51	7.94	8.11	8.75	n/a	n/a
5.0	8.52	7.85	7.87	8.38	n/a	n/a
5.5	8.56	7.86	7.79	8.12	8.74	n/a
6.0	8.62	7.94	7.73	7.81	8.42	n/a
6.5	8.69	7.89	7.66	7.80	8.20	8.75
7.0	8.80	7.96	7.73	7.80	8.07	8.56
7.5	8.86	8.01	7.77	7.78	7.95	8.39
8.0	9.02	8.12	7.82	7.80	7.93	8.28
8.5	9.14	8.21	7.88	7.81	7.97	8.19
9.0	9.26	8.33	7.99	7.90	8.00	8.12
9.5	9.40	8.45	8.08	7.99	8.03	8.17
10.0	9.55	8.55	8.17	8.07	8.07	8.23

Table E-24 Fuel cycle costs for plants with 30-day outage for the first 5 years with conversion costs increased to $10 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.31	8.43	8.44	9.00	n/a	n/a
5.0	9.34	8.37	8.21	8.62	n/a	n/a
5.5	9.38	8.37	8.16	8.37	9.31	n/a
6.0	9.46	8.37	8.10	8.17	8.82	n/a
6.5	9.52	8.43	8.05	8.09	8.41	8.81
7.0	9.64	8.50	8.12	8.10	8.28	8.72
7.5	9.72	8.55	8.17	8.09	8.17	8.57
8.0	9.87	8.58	8.21	8.09	8.19	8.46
8.5	9.98	8.77	8.30	8.13	8.22	8.38
9.0	10.11	8.90	8.40	8.22	8.25	8.31
9.5	10.27	9.01	8.49	8.31	8.29	8.38
10.0	10.41	9.14	8.59	8.38	8.31	8.45

Table E-25 Fuel cycle costs for plants with 15-day outage for the first 5 years with conversion costs increased to $13 a kilogram.

Enrichment wt% U^{235}	12 month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.58	8.02	8.21	8.81	n/a	n/a
5.0	8.59	7.94	7.98	8.48	n/a	n/a
5.5	8.64	7.93	7.88	8.22	8.96	n/a
6.0	8.70	7.93	7.82	8.01	8.54	n/a
6.5	8.77	7.97	7.77	7.90	8.31	8.88
7.0	8.85	8.04	7.82	7.90	8.16	8.68
7.5	8.97	8.10	7.87	7.89	8.08	8.51
8.0	9.10	8.21	7.91	7.90	8.04	8.39
8.5	9.22	8.30	7.98	7.91	8.08	8.31
9.0	9.34	8.42	8.09	8.01	8.11	8.24
9.5	9.49	8.54	8.18	8.09	8.14	8.28
10.0	9.64	8.65	8.27	8.17	8.18	8.35

Table E-26 Fuel cycle costs for plants with 30-day outage for the first 5 years with conversion costs increased to $13 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.43	8.57	8.59	9.16	n/a	n/a
5.0	9.46	8.51	8.36	8.79	n/a	n/a
5.5	9.50	8.51	8.31	8.54	9.11	n/a
6.0	9.58	8.51	8.25	8.34	8.60	n/a
6.5	9.65	8.57	8.20	8.25	8.59	9.11
7.0	9.77	8.64	8.27	8.26	8.46	8.92
7.5	9.85	8.69	8.32	8.25	8.34	8.79
8.0	10.00	8.82	8.36	8.26	8.36	8.65
8.5	10.13	8.92	8.46	8.30	8.36	8.56
9.0	10.25	9.05	8.56	8.39	8.43	8.60
9.5	10.42	9.18	8.65	8.48	8.46	8.57
10.0	10.57	9.30	8.78	8.56	8.49	8.64

Table E-27 Fuel cycle costs for plants with 15-day outage for the first 5 years with conversion costs decreased to $4 a kilogram

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mils/kWhr$_e$	18-month Fuel Cycle Cost mils/kWhr$_e$	24-month Fuel Cycle Cost mils/kWhr$_e$	30-month Fuel Cycle Cost mils/kWhr$_e$	36-month Fuel Cycle Cost mils/kWhr$_e$	42-month Fuel Cycle Cost mils/kWhr$_e$
4.5	8.36	7.77	7.82	8.56	n/a	n/a
5.0	8.37	7.68	7.69	8.18	n/a	n/a
5.5	8.41	7.68	7.60	7.91	8.50	n/a
6.0	8.47	7.67	7.54	7.71	8.18	n/a
6.5	8.53	7.72	7.50	7.60	7.98	8.50
7.0	8.64	7.79	7.54	7.60	7.85	8.32
7.5	8.72	7.84	7.59	7.59	7.73	8.16
8.0	8.85	7.94	7.63	7.59	7.72	8.04
8.5	8.96	8.03	7.66	7.61	7.75	7.96
9.0	9.08	8.14	7.73	7.70	7.78	7.90
9.5	9.22	8.25	7.86	7.78	7.82	7.94
10.0	9.36	8.36	7.97	7.85	7.85	8.00

Table E-28. Fuel cycle costs for plants with 30-day outage for the first 5 years with conversion costs decreased to $4 a kilogram.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.17	9.27	8.25	8.77	n/a	n/a
5.0	9.20	9.21	8.02	8.40	n/a	n/a
5.5	9.23	9.21	7.98	8.16	8.68	n/a
6.0	9.31	9.21	7.92	7.98	8.39	n/a
6.5	9.37	9.26	7.88	7.89	8.19	9.66
7.0	9.48	9.33	7.94	7.90	8.07	9.49
7.5	9.56	9.38	7.98	7.89	7.96	9.34
8.0	9.70	9.50	8.02	7.88	7.97	9.23
8.5	9.82	9.59	8.11	7.94	8.00	9.15
9.0	9.93	9.71	8.21	8.02	8.03	9.09
9.5	10.09	9.82	8.30	8.10	8.07	9.16
10.0	10.23	9.95	8.39	8.17	8.10	9.22

Table E-29 Fuel cycle costs for plants with 15-day outage for the first 5 years with enrichment costs decreased to $90 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.08	7.45	7.54	8.12	n/a	n/a
5.0	8.07	7.35	7.30	7.73	n/a	n/a
5.5	8.10	7.34	7.22	7.48	8.00	n/a
6.0	8.14	7.32	7.15	7.28	7.71	n/a
6.5	8.19	7.35	7.10	7.17	7.50	7.97
7.0	8.28	7.41	7.14	7.16	7.37	7.78
7.5	8.38	7.45	7.17	7.15	7.26	7.63
8.0	8.46	7.54	7.20	7.14	7.23	7.52
8.5	8.56	7.61	7.26	7.18	7.26	7.43
9.0	8.66	7.71	7.34	7.22	7.28	7.37
9.5	8.73	7.81	7.42	7.28	7.30	7.40
10.0	8.81	7.90	7.49	7.35	7.32	7.45

Table E-30 Fuel cycle costs for plants with 30-day outage for the first 5 years with enrichment costs decreased to $90 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.90	7.96	7.68	8.34	n/a	n/a
5.0	8.91	7.99	7.66	7.93	n/a	n/a
5.5	8.94	7.96	7.60	7.74	8.20	n/a
6.0	8.99	7.87	7.54	7.56	7.92	n/a
6.5	9.04	7.91	7.49	7.47	7.72	8.14
7.0	9.14	7.96	7.54	7.47	7.60	7.86
7.5	9.21	8.00	7.57	7.45	7.48	7.82
8.0	9.33	8.11	7.61	7.45	7.49	7.71
8.5	9.44	8.16	7.66	7.48	7.52	7.63
9.0	9.53	8.29	7.76	7.55	7.54	7.57
9.5	9.67	8.38	7.84	7.62	7.56	7.62
10.0	9.79	8.49	7.92	7.68	7.58	7.67

Table E-31. Fuel cycle costs for plants with 15-day outage for the first 5 years with enrichment costs decreased to \$80 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	7.80	7.25	7.31	7.84	n/a	n/a
5.0	7.69	7.16	7.07	7.46	n/a	n/a
5.5	7.61	7.13	6.99	7.21	7.70	n/a
6.0	7.64	7.10	6.91	7.01	7.41	n/a
6.5	7.69	7.13	6.86	6.90	7.20	7.64
7.0	8.07	7.16	6.83	6.88	7.08	7.46
7.5	8.13	7.21	6.81	6.87	6.96	7.31
8.0	8.23	7.28	6.84	6.86	6.94	7.20
8.5	8.32	7.35	6.99	6.87	6.96	7.11
9.0	8.41	7.44	7.06	6.93	6.97	7.05
9.5	8.53	7.53	7.13	7.00	6.99	7.07
10.0	8.64	7.62	7.20	7.05	7.01	7.12

Table E-32. Fuel cycle costs for plants with 30-day outage for the first 5 years with enrichment costs decreased to $80 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.73	7.78	7.68	8.07	n/a	n/a
5.0	8.73	7.69	7.44	7.72	n/a	n/a
5.5	8.75	7.67	7.37	7.48	7.90	n/a
6.0	8.80	7.66	7.30	7.30	7.62	n/a
6.5	8.84	7.69	7.25	7.21	7.43	7.81
7.0	8.93	7.73	7.30	7.20	7.31	7.64
7.5	8.99	7.77	7.32	7.18	7.20	7.50
8.0	9.10	7.86	7.36	7.18	7.20	7.39
8.5	9.20	7.93	7.42	7.20	7.22	7.31
9.0	9.29	8.03	7.49	7.27	7.24	7.25
9.5	9.41	8.11	7.56	7.33	7.25	7.30
10.0	9.53	8.22	7.63	7.38	7.27	7.34

Table E-33 Fuel cycle costs for plants with 15-day outage for the first 5 years with enrichment costs increased to $130 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	6.79	6.28	6.46	9.23	n/a	n/a
5.0	6.82	6.18	6.24	8.62	n/a	n/a
5.5	6.87	6.16	6.17	8.65	8.23	n/a
6.0	6.95	6.18	6.11	6.34	6.91	n/a
6.5	6.03	6.25	6.08	6.23	6.66	6.29
7.0	6.15	6.34	6.13	6.24	6.55	6.09
7.5	6.26	6.40	6.19	6.24	6.43	5.92
8.0	6.40	6.53	6.26	6.25	6.42	6.80
8.5	6.54	6.63	8.32	6.27	6.46	6.72
9.0	6.67	6.76	8.44	6.38	6.51	6.65
9.5	6.83	6.66	8.55	6.48	6.55	6.70
10.0	6.99	8.02	8.65	6.57	6.59	6.78

Table E-34 Fuel cycle costs for plants with 30-day outage for the first 5 years with enrichment costs increased to \$130 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.58	8.74	8.80	8.43	n/a	n/a
5.0	8.62	8.69	8.57	9.04	n/a	n/a
5.5	8.56	8.70	8.53	8.79	8.40	n/a
6.0	9.77	8.72	9.47	8.59	8.06	n/a
6.5	9.84	8.78	8.44	8.51	8.68	9.43
7.0	9.96	8.86	9.62	8.53	8.75	9.25
7.5	10.06	8.83	8.57	8.53	8.64	8.09
8.0	10.24	9.07	8.63	8.54	8.86	8.97
8.5	10.38	9.18	8.73	8.59	8.70	8.89
9.0	10.51	9.32	8.85	8.69	8.75	8.83
9.5	10.69	9.45	8.95	8.79	8.79	8.92
10.0	10.85	9.60	9.06	8.88	9.83	8.98

Table E-35 Fuel cycle costs for plants with 15-day outage for the first 5 years with enrichment costs increased to $150 a SWU

Enrichment	12-month Fuel Cycle Cost	18-month Fuel Cycle Cost	24-month Fuel Cycle Cost	30-month Fuel Cycle Cost	36-month Fuel Cycle Cost	42-month Fuel Cycle Cost
wt% U^{235}	$mills/kWhr_e$	$mills/kWhr_e$	$mills/kWhr_e$	$mills/kWhr_e$	$mills/kWhr_e$	$mills/kWhr_e$
4.5	9.15	8.67	8.96	9.79	n/a	n/a
5.0	9.19	8.80	8.71	9.36	n/a	n/a
5.5	9.26	8.62	8.64	9.08	9.84	n/a
6.0	9.35	8.53	8.59	8.87	9.51	n/a
6.5	9.44	8.70	8.56	8.76	9.27	9.95
7.0	9.59	8.80	8.63	8.78	9.13	9.74
7.5	9.70	8.88	8.70	8.79	9.01	9.57
8.0	9.87	9.02	8.77	8.80	9.01	9.45
8.5	10.02	9.14	8.86	8.83	9.07	9.36
9.0	10.17	9.29	8.96	8.96	9.12	9.30
9.5	10.38	9.44	9.12	9.07	9.17	9.36
10.0	10.54	9.68	9.23	9.17	9.22	9.45

Table E-36. Fuel cycle costs for plants with 30-day outage for the first 5 years with enrichment costs increased to $150 a SWU

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.92	9.14	9.25	9.97	n/a	n/a
5.0	9.96	9.10	9.02	9.57	n/a	n/a
5.5	10.05	9.12	9.96	9.31	10.00	n/a
6.0	10.15	9.14	9.94	9.11	9.88	n/a
6.5	10.25	9.22	9.91	9.03	9.46	10.08
7.0	10.40	9.32	9.00	9.05	9.33	9.83
7.5	10.51	9.39	9.07	9.06	9.21	9.72
8.0	10.69	9.56	9.14	9.06	9.24	9.91
8.5	10.85	9.68	9.26	9.15	9.30	9.53
9.0	11.00	9.84	9.39	9.28	9.35	9.46
9.5	11.20	9.98	9.51	9.37	9.40	9.56
10.0	11.39	10.15	9.63	9.47	9.45	9.65

Table E-37 Individual fuel cycle contributors reduced by 27% with corresponding percentage decrease in slope of in-core capital use charge.

Fuel Cycle Contributor	15-day outage			30-day outage		
	18-month % change	24-month % change	30-month % change	18-month % change	24-month % change	30-month % change
Feed	7.1	7.2	7.2	7.1	7.2	7.2
Conversion	1.2	1.2	1.2	1.2	1.2	1.2
Enrichment	17.9	17.9	17.8	17.4	17.8	17.7
Fabrication	0.5	0.6	0.5	0.6	0.9	0.5
Reload Licensing	0.7	0.5	0.4	0.7	0.9	0.4
Interest Rate	38.4	38.0	37.8	38.7	38.2	37.9

Table E-38. Fuel cycle costs for plants with 15-day outage for the first 5 years with fabrication costs increased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.50	7.92	8.10	8.77	n/a	n/a
5.0	8.50	7.83	7.84	8.35	n/a	n/a
5.5	8.54	7.82	7.76	8.08	8.70	n/a
6.0	8.59	7.81	7.69	7.87	8.38	n/a
6.5	8.65	7.85	7.64	7.75	8.15	8.70
7.0	8.76	7.92	7.66	7.75	8.02	8.50
7.5	8.85	7.97	7.72	7.74	7.89	8.33
8.0	8.87	8.07	7.77	7.74	7.88	8.21
8.5	9.08	8.18	7.83	7.75	7.91	8.13
9.0	9.20	8.27	7.93	7.84	7.94	9.08
9.5	9.34	8.39	8.02	7.92	7.97	8.09
10.0	9.48	8.48	8.11	8.00	8.00	8.16

Table E-39 Fuel cycle costs for plants with 30-day outage for the first 5 years with fabrication costs increased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.30	8.42	8.42	8.88	n/a	n/a
5.0	9.32	8.35	8.19	8.56	n/a	n/a
5.5	9.36	8.34	8.13	8.34	8.88	n/a
6.0	9.43	8.34	8.06	8.14	8.57	n/a
6.5	9.49	8.38	8.02	8.05	8.36	8.66
7.0	9.60	8.48	8.05	8.05	8.23	8.57
7.5	9.68	8.51	8.12	8.04	8.12	8.51
8.0	9.82	8.63	8.19	8.04	8.12	8.36
8.5	9.95	8.72	8.25	8.08	8.19	8.31
9.0	10.05	8.84	8.34	8.19	8.19	8.24
9.5	10.21	8.95	8.43	8.24	8.21	8.31
10.0	10.35	9.08	8.53	8.32	9.24	8.37

Table E-40 Fuel cycle costs for plants with 15-day outage for the first 5 years with fabrication costs increased by 20%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.56	8.00	8.18	8.87	n/a	n/a
5.0	8.58	7.69	7.91	8.44	n/a	n/a
5.5	8.59	7.68	7.82	8.15	8.78	n/a
6.0	8.64	7.68	7.75	7.93	8.45	n/a
6.5	8.70	7.80	7.69	7.81	8.21	8.77
7.0	8.80	7.96	7.73	7.81	8.07	8.56
7.5	8.89	8.01	7.77	7.79	7.95	8.39
8.0	9.01	8.12	7.81	7.78	7.92	8.27
8.5	9.12	8.20	7.87	7.80	7.95	8.17
9.0	9.24	8.31	7.97	7.88	7.98	8.10
9.5	9.38	8.42	8.06	7.96	8.01	8.14
10.0	9.52	8.53	8.14	8.04	8.04	8.20

Table E-41 Fuel cycle costs for plants with 30-day outage for the first 5 years with fabrication costs increased by 20%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.36	8.48	8.50	9.07	n/a	n/a
5.0	9.37	8.41	8.25	8.67	n/a	n/a
5.5	9.41	8.40	8.19	8.41	8.96	n/a
6.0	9.47	8.39	8.12	8.20	8.64	n/a
6.5	9.53	8.44	8.07	8.10	8.42	8.92
7.0	9.64	8.50	8.12	8.10	8.29	8.73
7.5	9.72	8.55	8.18	8.09	8.17	8.57
8.0	9.86	8.67	8.20	8.08	8.17	8.45
8.5	9.98	8.76	8.29	8.12	8.20	8.36
9.0	10.09	8.88	8.38	8.21	8.23	8.29
9.5	10.25	8.99	8.47	8.28	8.26	8.36
10.0	10.39	9.11	8.56	8.35	8.28	8.42

Table E-42 Fuel cycle costs for plants with 15-day outage for the first 5 years with fabrication costs decreased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.37	7.78	7.63	8.68	n/a	n/a
5.0	8.38	7.71	7.70	8.16	n/a	n/a
5.5	8.43	7.71	7.64	7.94	8.53	n/a
6.0	8.50	7.71	7.58	7.75	8.23	n/a
6.5	8.57	7.75	7.54	7.64	8.03	8.56
7.0	8.68	7.83	7.58	7.65	7.90	8.37
7.5	8.77	7.88	7.63	7.64	7.79	8.22
8.0	8.89	7.89	7.68	7.65	7.78	8.11
8.5	9.01	8.08	7.75	7.67	7.81	8.03
9.0	9.13	8.20	7.85	7.76	7.85	7.98
9.5	9.27	8.31	7.95	7.85	7.68	8.01
10.0	9.42	8.42	8.03	7.92	7.92	8.07

Table E-43 Fuel cycle costs for plants with 30-day outage for the first 5 years with fabrication costs decreased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.18	8.28	8.26	8.73	n/a	n/a
5.0	9.21	8.23	8.05	8.43	n/a	n/a
5.5	9.26	8.24	8.00	8.20	8.72	n/a
6.0	9.33	8.24	7.95	8.01	8.43	n/a
6.5	9.40	8.30	7.91	7.94	8.24	8.72
7.0	9.52	8.37	7.98	7.88	8.12	8.54
7.5	9.60	8.42	8.03	7.94	8.01	8.40
8.0	9.75	8.55	8.08	7.89	8.03	8.28
8.5	9.87	8.64	8.17	7.99	8.08	8.21
9.0	9.98	8.77	8.27	8.08	8.10	8.15
9.5	10.15	8.88	8.36	8.17	8.13	8.23
10.0	10.29	9.01	8.45	8.24	8.18	8.28

Table E-44 Fuel cycle costs for plants with 15-day outage for the first 5 years with fabrication costs decreased by 20%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.31	7.71	7.65	8.48	n/a	n/a
5.0	8.33	7.64	7.63	8.11	n/a	n/a
5.5	8.38	7.65	7.57	7.87	8.45	n/a
6.0	8.45	7.65	7.52	7.68	8.16	n/a
6.5	8.52	7.71	7.49	7.58	7.96	8.49
7.0	8.63	7.79	7.54	7.60	7.84	8.31
7.5	8.73	7.84	7.59	7.60	7.74	8.18
8.0	8.85	7.95	7.64	7.60	7.73	8.05
8.5	8.98	8.04	7.71	7.62	7.77	7.98
9.0	9.08	8.18	7.81	7.72	7.81	7.92
9.5	9.24	8.28	7.81	7.81	7.84	7.96
10.0	9.38	8.39	8.00	7.86	7.88	8.03

Table E-45 Fuel cycle costs for plants with 30-day outage for the first 5 years with fabrication costs decreased by 20%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.12	8.22	8.18	8.70	n/a	n/a
5.0	8.18	8.17	7.98	8.35	n/a	n/a
5.5	8.21	8.16	7.84	8.13	8.64	n/a
6.0	8.29	8.16	7.89	7.98	8.36	n/a
6.5	8.36	8.25	7.86	7.88	8.17	8.85
7.0	8.48	8.32	7.83	7.89	8.08	8.46
7.5	8.57	8.38	7.93	7.86	7.98	8.34
8.0	8.71	8.51	8.03	7.90	7.98	8.24
8.5	8.84	8.61	8.13	7.96	8.02	8.17
9.0	8.95	8.73	8.23	8.04	8.06	8.11
9.5	10.11	8.84	8.32	8.13	8.06	8.18
10.0	10.25	8.97	8.42	8.20	8.13	8.25

Table E-46 Fuel cycle costs for plants with 15-day outage for the first 5 years with reload licensing costs decreased by 25%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.40	7.83	8.00	8.66	n/a	n/a
5.0	8.41	7.74	7.75	8.28	n/a	n/a
5.5	8.45	7.74	7.68	8.00	8.60	n/a
6.0	8.51	7.73	7.61	7.78	8.29	n/a
6.5	8.57	7.77	7.57	7.68	8.08	8.62
7.0	8.68	7.84	7.61	7.68	7.95	8.43
7.5	8.76	7.90	7.66	7.68	7.83	8.26
8.0	8.89	8.00	7.70	7.68	7.81	8.15
8.5	9.00	8.09	7.77	7.69	7.85	8.06
9.0	9.12	8.20	7.87	7.78	7.88	8.00
9.5	9.26	8.32	7.96	7.87	7.91	8.04
10.0	9.40	8.42	8.05	7.94	7.94	8.10

Table E-47 Fuel cycle costs for plants with 30-day outage for the first 5 years with reload licensing costs decreased by 25%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.20	9.33	9.32	9.97	n/a	n/a
5.0	9.23	9.27	8.10	9.49	n/a	n/a
5.5	9.27	9.29	8.06	8.25	9.78	n/a
6.0	9.34	9.27	7.99	8.06	8.49	n/a
6.5	9.40	9.32	7.95	7.98	8.26	9.77
7.0	9.52	9.39	8.01	7.98	8.16	8.59
7.5	9.60	9.44	8.05	7.97	8.08	8.44
8.0	9.74	9.56	8.10	7.98	8.06	8.33
8.5	9.86	9.65	8.19	8.02	8.10	8.25
9.0	9.97	9.77	8.28	8.11	8.13	8.19
9.5	10.13	9.88	8.37	8.19	8.19	8.26
10.0	10.27	9.01	8.47	8.26	8.19	8.32

Table E-48 Fuel cycle costs for plants with 15-day outage for the first 5 years with reload licensing costs decreased by 50%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.36	7.81	7.98	8.65	n/a	n/a
5.0	8.37	7.72	7.74	8.24	n/a	n/a
5.5	8.41	7.71	7.66	7.98	8.59	n/a
6.0	8.47	7.71	7.59	7.76	8.28	n/a
6.5	8.53	7.75	7.55	7.87	8.08	8.81
7.0	8.63	7.82	7.59	7.67	7.93	8.41
7.5	8.72	7.87	7.64	7.68	7.82	8.25
8.0	8.84	7.88	7.68	7.66	7.80	8.14
8.5	8.98	8.06	7.75	7.68	7.83	8.05
9.0	9.07	8.17	7.85	7.77	7.86	7.99
9.5	9.21	8.28	7.94	7.85	7.90	8.03
10.0	9.35	8.39	8.02	7.92	7.93	8.08

Table E-49 Fuel cycle costs for plants with 30-day outage for the first 5 years with reload licensing costs decreased by 50%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.17	8.30	8.30	8.86	n/a	n/a
5.0	9.16	8.24	8.08	8.48	n/a	n/a
5.5	9.23	8.24	8.03	8.24	8.77	n/a
6.0	9.30	8.24	7.97	8.04	8.48	n/a
6.5	9.36	8.29	7.93	7.96	8.27	8.76
7.0	9.47	8.36	7.99	7.95	8.18	8.58
7.5	9.56	8.41	8.03	7.96	8.04	8.43
8.0	9.69	8.53	8.07	7.96	8.05	8.32
8.5	9.82	8.62	8.18	8.00	8.08	8.24
9.0	9.93	8.74	8.28	8.09	8.11	8.18
9.5	10.08	8.85	8.35	8.17	8.14	8.24
10.0	10.22	8.88	8.44	8.24	8.17	8.31

Table E-50. Fuel cycle costs for plants with 15-day outage for the first 5 years with reload licensing costs increased by 25%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.47	7.88	8.03	8.83	n/a	n/a
5.0	8.48	7.73	7.79	8.29	n/a	n/a
5.5	8.52	7.73	7.72	8.03	8.83	n/a
6.0	8.59	7.78	7.68	7.82	8.32	n/a
6.5	8.65	7.83	7.81	7.71	8.10	8.64
7.0	8.76	7.90	7.65	7.72	7.97	8.45
7.5	8.85	7.95	7.70	7.71	7.88	8.28
8.0	8.89	8.09	7.75	7.71	7.84	8.17
8.5	9.10	8.15	7.81	7.73	7.87	8.03
9.0	9.21	8.28	7.81	7.82	7.81	8.02
9.5	9.36	8.38	8.01	7.80	7.84	8.06
10.0	9.50	8.49	8.09	7.86	7.87	8.13

Table E-51. Fuel cycle costs for plants with 30-day outage for the first 5 years with reload licensing costs increased by 25%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.28	8.36	8.38	8.90	n/a	n/a
5.0	9.31	8.32	8.13	8.52	n/a	n/a
5.5	9.35	8.32	8.08	8.28	8.81	n/a
6.0	9.42	8.32	8.03	8.09	8.52	n/a
6.5	9.48	8.37	7.98	8.01	8.31	8.90
7.0	9.60	8.44	8.05	8.01	8.16	8.62
7.5	9.69	8.48	8.10	8.01	8.08	8.46
8.0	9.83	8.62	8.14	8.01	8.09	8.38
8.5	9.96	8.71	8.23	8.05	8.12	8.27
9.0	10.07	8.83	8.33	8.14	8.18	8.21
9.5	10.23	8.95	8.42	8.22	8.16	8.28
10.0	10.37	9.06	8.51	8.30	8.22	8.35

Table E-52   Fuel cycle costs for plants with 15-day outage for the first 5 years with reload licensing costs increased by 50%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.51	7.90	8.05	8.70	n/a	n/a
5.0	8.52	7.82	7.81	8.30	n/a	n/a
5.5	8.56	7.82	7.74	8.04	8.64	n/a
6.0	8.63	7.81	7.67	7.84	8.33	n/a
6.5	8.69	7.86	7.63	7.73	8.12	8.65
7.0	8.80	7.93	7.67	7.73	7.99	8.46
7.5	8.89	7.98	7.72	7.73	7.87	8.30
8.0	9.02	8.09	7.77	7.73	7.85	8.18
8.5	9.14	8.18	7.83	7.74	7.88	8.10
9.0	9.26	8.29	7.94	7.84	7.92	8.03
9.5	9.41	8.41	8.03	7.92	7.95	8.08
10.0	9.55	8.52	8.12	8.00	7.98	8.14

Table E-53 Fuel cycle costs for plants with 30-day outage for the first 5 years with reload licensing costs increased by 50%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.32	8.40	8.39	8.91	n/a	n/a
5.0	9.35	8.34	8.15	8.54	n/a	n/a
5.5	9.39	8.34	8.10	8.30	8.62	n/a
6.0	9.48	8.34	8.04	8.11	8.53	n/a
6.5	9.53	8.40	8.00	8.02	8.32	8.91
7.0	9.65	8.47	8.07	8.03	8.20	8.63
7.5	9.73	8.52	8.12	8.02	8.09	8.48
8.0	9.88	8.65	8.18	8.03	8.10	8.37
8.5	10.00	8.74	8.25	8.07	8.14	8.28
9.0	10.11	8.87	8.35	8.16	8.17	8.22
9.5	10.28	8.98	8.44	8.24	8.20	8.28
10.0	10.42	9.11	8.54	8.31	8.23	8.38

Table E-54 Fuel cycle costs for plants with 15-day outage for the first 5 years with replacement power costs increased to $30\ \frac{mils}{kW\ hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.64	7.69	8.12	8.78	n/a	n/a
5.0	8.65	7.81	7.87	8.35	n/a	n/a
5.5	8.69	7.90	7.80	8.10	8.88	n/a
6.0	8.75	7.88	7.74	7.89	8.37	n/a
6.5	8.82	7.94	7.69	7.78	8.16	8.69
7.0	8.92	8.01	7.74	7.78	8.03	8.50
7.5	9.01	8.06	7.76	7.76	7.81	8.34
8.0	9.14	8.17	7.83	7.76	7.90	8.22
8.5	9.26	8.26	7.88	7.79	7.93	8.14
9.0	9.37	8.37	7.98	7.88	7.99	8.07
9.5	9.52	8.49	8.09	7.97	7.99	8.11
10.0	9.66	8.59	8.17	8.04	8.02	8.16

Table E-55 Fuel cycle costs for plants with 30-day outage for the first 5 years with replacement power costs increased to $30\ \frac{mils}{kW\text{-}hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.65	8.63	8.55	9.05	n/a	n/a
5.0	9.68	8.57	8.32	8.67	n/a	n/a
5.5	9.72	8.56	8.27	8.43	8.93	n/a
6.0	9.78	8.57	8.21	8.24	8.64	n/a
6.5	9.85	8.62	8.17	8.16	8.43	8.90
7.0	9.97	8.69	8.24	8.16	8.31	8.72
7.5	10.05	8.74	8.28	8.15	8.20	8.57
8.0	10.20	8.86	8.32	8.18	8.21	8.46
8.5	10.32	8.96	8.41	8.20	8.28	8.38
9.0	10.43	9.08	8.51	8.29	8.28	8.32
9.5	10.58	9.19	8.60	8.37	8.31	8.39
10.0	10.73	9.32	8.69	8.44	8.34	8.45

Table E-56 Fuel cycle costs for plants with 15-day outage for the first 5 years with replacement power costs increased to $50\ \frac{mils}{kW\ hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mils/kWhr$_e$	18-month Fuel Cycle Cost mils/kWhr$_e$	24-month Fuel Cycle Cost mils/kWhr$_e$	30-month Fuel Cycle Cost mils/kWhr$_e$	36-month Fuel Cycle Cost mils/kWhr$_e$	42 month Fuel Cycle Cost mils/kWhr$_e$
4.5	9.48	8.54	8.63	9.08	n/a	n/a
5.0	9.47	8.45	8.29	8.68	n/a	n/a
5.5	9.51	8.45	8.21	8.42	8.96	n/a
6.0	9.57	8.44	8.15	8.22	8.65	n/a
6.5	9.64	8.49	8.10	8.11	8.43	8.92
7.0	9.75	8.56	8.15	8.11	8.30	8.73
7.5	9.83	8.61	8.19	8.10	8.18	8.57
8.0	9.96	8.72	8.24	8.11	8.17	8.45
8.5	10.08	8.81	8.30	8.12	8.20	8.37
9.0	10.19	8.92	8.40	8.21	8.24	8.30
9.5	10.34	9.03	8.50	8.30	8.27	8.34
10.0	10.48	9.14	8.59	8.37	8.30	8.41

Table E-57 Fuel cycle costs for plants with 30-day outage for the first 5 years with replacement power costs increased to $50\ \frac{mils}{kW \cdot hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	11.30	9.72	9.37	9.71	n/a	n/a
5.0	11.32	9.66	9.14	9.33	n/a	n/a
5.5	11.38	9.66	9.06	9.08	9.49	n/a
6.0	11.44	9.68	9.03	8.90	9.19	n/a
6.5	11.50	9.72	8.99	8.81	8.99	9.37
7.0	11.61	9.79	9.06	8.82	8.86	9.19
7.5	11.70	9.84	9.10	8.81	8.75	9.04
8.0	11.84	9.96	9.14	8.81	8.76	8.93
8.5	11.96	10.05	9.23	8.86	8.79	8.85
9.0	12.07	10.17	9.33	8.95	8.83	8.79
9.5	12.23	10.28	9.42	9.03	8.86	8.86
10.0	12.37	10.41	9.52	9.10	8.89	8.92

Table E-58 Fuel cycle costs for plants with 15-day outage for the first 5 years with replacement power costs decreased to $20\ \frac{mils}{kW\ hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mils/kWhr$_e$	18-month Fuel Cycle Cost mils/kWhr$_e$	24-month Fuel Cycle Cost mils/kWhr$_e$	30-month Fuel Cycle Cost mils/kWhr$_e$	36-month Fuel Cycle Cost mils/kWhr$_e$	42-month Fuel Cycle Cost mils/kWhr$_e$
4.5	8.02	7.58	7.61	8.51	n/a	n/a
5.0	8.03	7.48	7.57	8.11	n/a	n/a
5.5	8.07	7.48	7.49	7.85	8.48	n/a
6.0	8.14	7.48	7.43	7.64	8.17	n/a
6.5	8.20	7.53	7.38	7.53	7.85	8.51
7.0	8.31	7.60	7.43	7.54	7.82	8.32
7.5	8.40	7.65	7.47	7.53	7.71	8.18
8.0	8.52	7.78	7.52	7.53	7.68	8.04
8.5	8.64	7.85	7.58	7.54	7.72	7.98
9.0	8.76	7.98	7.69	7.64	7.76	7.89
9.5	8.90	8.08	7.78	7.72	7.78	7.83
10.0	8.94	8.18	7.67	7.80	7.82	8.00

Table E-59 Fuel cycle costs for plants with 30-day outage for the first 5 years with replacement power costs decreased to $20\ \frac{mils}{kW\ hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.83	9.08	8.13	9.72	n/a	n/a
5.0	8.86	8.02	7.91	9.34	n/a	n/a
5.5	8.80	9.02	7.86	9.10	8.65	n/a
6.0	8.87	8.02	7.80	7.91	8.37	n/a
6.5	9.03	9.07	7.79	7.93	9.19	9.67
7.0	9.15	8.14	7.82	7.83	8.04	9.49
7.5	8.23	8.19	7.87	7.93	7.93	9.33
8.0	8.37	8.31	7.81	7.83	7.94	9.22
8.5	9.50	8.41	8.00	7.87	7.87	9.14
9.0	9.61	8.53	8.10	7.96	9.01	9.08
9.5	9.77	8.64	8.19	8.04	8.04	9.19
10.0	8.91	8.77	9.28	8.11	9.07	9.22

Table E-60 Fuel cycle costs for plants with 15-day outage for the first 5 years with replacement power costs decreased to $15\ \frac{mils}{kW\ hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.02	7.58	7.91	8.51	n/a	n/a
5.0	8.03	7.49	7.57	8.11	n/a	n/a
5.5	8.07	7.49	7.48	7.86	8.48	n/a
6.0	8.14	7.48	7.43	7.64	8.17	n/a
6.5	8.20	7.53	7.38	7.53	7.95	8.51
7.0	8.31	7.60	7.43	7.54	7.82	8.32
7.5	8.40	7.65	7.47	7.53	7.71	8.16
8.0	8.52	7.78	7.52	7.63	7.69	8.04
8.5	8.64	7.85	7.58	7.54	7.72	7.99
9.0	8.76	7.96	7.69	7.84	7.78	7.89
9.5	8.90	8.08	7.78	7.72	7.78	7.93
10.0	9.04	8.18	7.87	7.80	7.82	8.00

Table E-61 Fuel cycle costs for plants with 30-day outage for the first 5 years with replacement power costs decreased to $15 \frac{mils}{kW \cdot hr_e}$

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.42	7.80	7.93	8.56	n/a	n/a
5.0	8.45	7.74	7.70	8.18	n/a	n/a
5.5	8.49	7.74	7.68	7.94	8.52	n/a
6.0	8.56	7.74	7.59	7.75	8.23	n/a
6.5	8.62	7.80	7.55	7.68	8.02	8.55
7.0	8.74	7.88	7.62	7.67	7.90	8.37
7.5	8.82	7.92	7.66	7.68	7.78	8.22
8.0	8.96	8.04	7.71	7.66	7.80	8.11
8.5	9.09	8.14	7.80	7.71	7.84	8.03
9.0	9.20	8.26	7.96	7.79	7.87	7.98
9.5	9.36	8.37	7.98	7.88	7.90	8.03
10.0	9.50	8.50	8.06	7.95	7.93	8.10

Table E-82 Fuel cycle costs for plants with 15-day outage for the first 5 years with dry cask storage costs increased by 10%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36 month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.45	7.88	8.04	8.71	n/a	n/a
5.0	8.48	7.79	7.78	8.30	n/a	n/a
5.5	8.50	7.78	7.72	8.04	8.64	n/a
6.0	8.56	7.77	7.65	7.83	8.33	n/a
6.5	8.62	7.82	7.61	7.72	8.11	8.65
7.0	8.73	7.89	7.65	7.72	7.98	8.46
7.5	8.82	7.94	7.68	7.71	7.86	8.29
8.0	8.94	8.05	7.74	7.71	7.84	8.18
8.5	9.06	8.13	7.80	7.72	7.87	8.09
9.0	9.18	8.24	7.90	7.81	7.81	8.02
9.5	9.32	8.38	7.99	7.90	7.84	8.06
10.0	9.46	8.47	8.08	7.97	7.97	8.13

Table E-63 Fuel cycle costs for plants with 30-day outage for the first 5 years with dry cask storage costs increased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.28	8.37	8.37	8.92	n/a	n/a
5.0	8.28	8.31	8.14	8.54	n/a	n/a
5.5	8.32	8.31	8.09	8.29	8.82	n/a
6.0	8.38	8.31	8.02	8.09	8.53	n/a
6.5	8.48	8.38	7.98	8.01	8.32	8.81
7.0	8.57	8.43	8.04	8.01	8.18	8.62
7.5	8.65	8.48	8.09	8.00	8.08	8.47
8.0	8.80	8.60	8.13	8.01	8.03	8.36
8.5	9.32	8.69	8.22	8.06	8.12	8.28
9.0	10.03	8.81	8.31	8.13	8.15	8.21
9.5	10.18	8.92	8.40	8.22	8.13	8.28
10.0	10.33	9.05	8.50	8.28	8.21	8.34

Table E-64 Fuel cycle costs for plants with 15-day outage for the first 5 years with dry cask storage costs increased by 20%.

Enrichment w/% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.47	7.80	8.07	8.74	n/a	n/a
5.0	8.48	7.81	7.82	8.33	n/a	n/a
5.5	8.52	7.80	7.74	8.06	8.67	n/a
6.0	8.57	7.78	7.67	7.95	8.35	n/a
6.5	8.64	7.83	7.62	7.73	8.13	8.87
7.0	8.74	7.90	7.58	7.73	7.99	8.48
7.5	8.83	7.95	7.71	7.72	7.87	8.31
8.0	8.95	8.06	7.75	7.72	7.86	8.19
8.5	9.07	8.14	7.81	7.73	7.89	8.11
9.0	9.18	8.25	7.81	7.82	7.92	8.04
9.5	9.33	8.37	8.00	7.91	7.95	8.06
10.0	9.47	8.47	8.09	7.88	7.98	8.14

Table E-65 Fuel cycle costs for plants with 30-day outage for the first 5 years with dry cask storage costs increased by 20%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.28	8.40	8.39	8.95	n/a	n/a
5.0	9.30	8.33	8.18	8.56	n/a	n/a
5.5	9.34	8.32	8.11	8.31	8.85	n/a
6.0	9.41	8.32	8.04	8.11	8.55	n/a
6.5	9.47	8.37	8.00	8.03	8.34	8.83
7.0	9.58	8.44	8.06	8.03	8.21	8.64
7.5	9.66	8.49	8.10	8.02	8.10	8.49
8.0	9.81	8.61	8.14	8.02	8.11	8.37
8.5	9.93	8.70	8.23	8.06	8.14	8.29
9.0	10.04	8.82	8.33	8.15	8.17	8.23
9.5	10.20	8.93	8.41	8.23	8.20	8.29
10.0	10.34	9.06	8.51	8.30	8.22	8.36

Table E-66 Fuel cycle costs for plants with 15-day outage for the first 5 years with dry cask storage costs increased by 50%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.53	7.87	8.15	8.84	n/a	n/a
5.0	8.53	7.67	7.89	8.41	n/a	n/a
5.5	8.56	7.65	7.80	8.13	8.75	n/a
6.0	8.62	7.64	7.72	7.91	8.42	n/a
6.5	8.67	7.87	7.67	7.79	8.19	8.74
7.0	8.78	7.94	7.71	7.78	8.05	8.54
7.5	8.86	7.96	7.75	7.77	7.92	8.37
8.0	8.96	8.09	7.79	7.76	7.90	8.24
8.5	9.10	8.18	7.85	7.77	7.93	8.15
9.0	9.21	8.28	7.94	7.86	7.96	8.08
9.5	9.35	8.40	8.03	7.94	7.98	8.11
10.0	9.49	8.50	8.12	8.01	8.01	8.17

Table E-67 Fuel cycle costs for plants with 30-day outage for the first 5 years with dry cask storage costs increased by 50%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.34	8.46	8.47	9.05	n/a	n/a
5.0	9.35	8.39	8.23	8.64	n/a	n/a
5.5	9.38	8.35	8.18	8.38	8.93	n/a
6.0	9.45	8.37	8.09	8.17	8.62	n/a
6.5	9.50	8.41	8.04	8.08	8.40	8.90
7.0	9.62	8.46	8.10	8.08	8.26	8.70
7.5	9.70	8.52	8.14	8.06	8.14	8.54
8.0	9.83	8.64	8.18	8.06	8.15	8.42
8.5	9.96	8.73	8.28	8.10	8.18	8.33
9.0	10.08	8.85	8.38	8.18	8.20	8.27
9.5	10.22	8.96	8.44	8.28	8.23	8.33
10.0	10.35	9.09	8.54	8.33	8.26	8.39

Table E-68. Fuel cycle costs for plants with 15-day outage for the first 5 years with dry cask storage costs decreased by 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.41	7.83	7.99	8.84	n/a	n/a
5.0	8.43	7.75	7.75	8.24	n/a	n/a
5.5	8.47	7.75	7.58	7.89	8.53	n/a
6.0	8.53	7.74	7.62	7.79	8.28	n/a
6.5	8.60	7.79	7.57	7.88	8.07	8.60
7.0	8.71	7.86	7.62	7.66	7.94	8.42
7.5	8.80	7.91	7.87	7.68	7.83	8.28
8.0	8.92	8.02	7.71	7.69	7.81	8.14
8.5	9.04	8.11	7.78	7.70	7.85	8.06
9.0	9.18	8.22	7.88	7.79	7.88	8.00
9.5	9.30	8.34	7.87	7.87	7.81	8.04
10.0	9.44	8.48	8.08	7.95	7.94	8.10

Table E-69 Fuel cycle costs for plants with 30-day outage for the first 5 years with dry cask storage costs decreased by 10%.

Enrichment wt% U^{235}	12 month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.22	8.33	8.31	8.85	n/a	n/a
5.0	9.28	8.27	8.09	8.48	n/a	n/a
5.5	9.29	8.27	8.05	8.24	8.77	n/a
6.0	9.37	8.28	7.99	8.08	8.46	n/a
6.5	9.43	8.33	7.95	7.98	8.28	8.76
7.0	9.55	8.40	8.02	7.98	8.18	8.59
7.5	9.63	8.48	8.08	7.98	8.08	8.43
8.0	9.78	8.56	8.11	7.98	8.08	8.33
8.5	9.90	8.67	8.20	8.02	8.10	8.25
9.0	10.01	8.78	8.28	8.11	8.13	8.19
9.5	10.17	8.91	8.38	8.18	8.16	8.26
10.0	10.31	9.04	8.48	8.27	8.18	8.32

Table E-70 Fuel cycle costs for plants with 15-day outage for the first 5 years with dry cask storage costs decreased by 20%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.38	7.81	7.96	8.81	n/a	n/a
5.0	8.41	7.73	7.72	8.22	n/a	n/a
5.5	8.45	7.73	7.66	7.97	8.56	n/a
6.0	8.52	7.73	7.60	7.77	8.26	n/a
6.5	8.58	7.77	7.56	7.68	8.05	8.58
7.0	8.68	7.85	7.60	7.67	7.92	8.40
7.5	8.78	7.90	7.65	7.66	7.81	8.24
8.0	8.91	8.01	7.70	7.67	7.80	8.13
8.5	9.03	8.10	7.77	7.68	7.83	8.05
9.0	9.15	8.21	7.87	7.78	7.87	7.98
9.5	9.29	8.33	7.96	7.86	7.90	8.03
10.0	9.44	8.44	8.05	7.94	7.93	8.09

Table E-71 Fuel cycle costs for plants with 30-day outage for the first 5 years with dry cask storage costs decreased by 20%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.20	8.31	8.29	8.62	n/a	n/a
5.0	9.23	8.28	8.07	8.48	n/a	n/a
5.5	9.28	8.28	8.03	8.22	8.74	n/a
6.0	9.35	8.28	7.97	8.04	8.48	n/a
6.5	9.42	8.32	7.93	7.96	8.26	8.74
7.0	9.54	8.39	8.00	7.97	8.14	8.57
7.5	9.62	8.44	8.05	7.96	8.03	8.42
8.0	9.77	8.57	8.09	7.97	8.05	8.31
8.5	9.89	8.66	8.18	8.01	8.08	8.23
9.0	10.00	8.78	8.28	8.10	8.12	8.17
9.5	10.18	8.90	8.37	8.18	8.18	8.24
10.0	10.30	9.03	8.47	8.26	8.18	8.31

Table E-72. Fuel cycle costs for plants with 15-day outage for the first 5 years with revised disposal fee assessment

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24 month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.09	7.95	8.70	10.25	n/a	n/a
5.0	9.02	7.74	8.26	9.33	n/a	n/a
5.5	9.01	7.61	7.96	8.79	10.14	n/a
6.0	9.02	7.53	7.75	8.39	9.40	n/a
6.5	9.05	7.50	7.61	8.11	8.92	10.11
7.0	9.13	7.51	7.56	7.95	8.62	9.57
7.5	9.19	7.53	7.52	7.83	8.37	9.17
8.0	9.28	7.59	7.51	7.75	8.22	8.89
8.5	9.38	7.66	7.53	7.70	8.12	8.69
9.0	9.49	7.73	7.56	7.72	8.06	8.52
9.5	9.62	7.82	7.63	7.74	8.02	8.44
10.0	9.75	7.90	7.69	7.77	7.98	8.40

Table E-73 Fuel cycle costs for plants with 30-day outage for the first 5 years with revised disposal fee assessment.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.88	8.41	8.87	10.33	n/a	n/a
5.0	8.84	8.22	8.56	9.46	n/a	n/a
5.5	8.83	8.11	8.28	8.98	10.22	n/a
6.0	8.86	8.04	8.08	8.62	9.53	n/a
6.5	8.89	8.03	7.96	8.38	9.08	10.18
7.0	8.98	8.05	7.93	8.22	8.78	9.67
7.5	9.04	8.06	7.90	8.10	8.56	9.30
8.0	9.16	8.14	7.89	8.03	8.43	9.04
8.5	9.27	8.20	7.93	8.00	8.34	8.84
9.0	9.36	8.29	7.96	8.02	8.28	8.69
9.5	9.51	8.38	8.03	8.04	8.25	8.62
10.0	9.63	8.49	8.10	8.07	8.22	8.56

Table E-74. Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates decreased to 6%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.28	7.70	7.86	8.51	n/a	n/a
5.0	8.27	7.60	7.61	8.09	n/a	n/a
5.5	8.30	7.58	7.51	7.82	8.42	n/a
6.0	8.34	7.55	7.43	7.60	8.09	n/a
6.5	8.38	7.58	7.37	7.48	7.95	8.39
7.0	8.46	7.62	7.38	7.45	7.71	8.18
7.5	8.53	7.66	7.41	7.43	7.59	8.00
8.0	8.62	7.74	7.44	7.41	7.56	7.87
8.5	8.72	7.80	7.48	7.41	7.55	7.77
9.0	8.80	7.88	7.55	7.47	7.58	7.70
9.5	8.91	7.97	7.62	7.52	7.57	7.70
10.0	9.02	8.05	7.68	7.57	7.58	7.74

Table E-75 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates decreased to 6%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.08	8.20	8.16	8.72	n/a	n/a
5.0	9.10	8.12	7.95	8.33	n/a	n/a
5.5	9.12	8.10	7.88	8.07	8.60	n/a
6.0	9.17	8.09	7.80	7.87	8.28	n/a
6.5	9.21	8.12	7.75	7.77	8.08	8.55
7.0	9.30	8.18	7.78	7.75	7.93	8.35
7.5	9.36	8.20	7.80	7.72	7.81	8.18
8.0	9.47	8.29	7.83	7.71	7.79	8.05
8.5	9.57	8.36	7.88	7.73	7.80	7.96
9.0	9.65	8.45	7.96	7.79	7.81	7.88
9.5	9.77	8.53	8.02	7.84	7.82	7.92
10.0	9.88	8.83	8.08	7.89	7.83	7.88

Table E-76 Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates decreased to 5%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18 month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.14	7.56	7.70	8.35	n/a	n/a
5.0	8.11	7.44	7.45	7.81	n/a	n/a
5.5	8.12	7.40	7.33	7.63	8.23	n/a
6.0	8.14	7.38	7.23	7.41	7.88	n/a
6.5	8.17	7.37	7.18	7.27	7.63	8.17
7.0	8.23	7.40	7.18	7.23	7.48	7.94
7.5	8.28	7.41	7.18	7.18	7.35	7.74
8.0	8.35	7.47	7.17	7.15	7.29	7.60
8.5	8.41	7.51	7.19	7.13	7.26	7.49
9.0	8.48	7.57	7.24	7.16	7.25	7.40
9.5	8.56	7.63	7.28	7.19	7.24	7.39
10.0	8.64	7.69	7.32	7.22	7.24	7.39

Table E-77 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates decreased to 5%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36 month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.85	8.06	8.03	8.56	n/a	n/a
5.0	8.94	7.97	7.79	8.18	n/a	n/a
5.5	8.95	7.93	7.70	7.89	8.41	n/a
6.0	8.97	7.90	7.81	7.68	8.08	n/a
6.5	9.00	7.91	7.54	7.56	7.85	8.33
7.0	9.07	7.93	7.55	7.52	7.70	8.11
7.5	9.11	7.98	7.56	7.47	7.57	7.92
8.0	9.19	8.02	7.56	7.45	7.53	7.78
8.5	9.26	8.06	7.60	7.45	7.51	7.58
9.0	9.32	8.13	7.65	7.48	7.50	7.80
9.5	9.41	8.18	7.69	7.51	7.48	7.80
10.0	9.49	8.28	7.73	7.53	7.48	7.80

Table E-78 Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates increased to 8%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	8.58	8.02	8.18	8.85	n/a	n/a
5.0	8.62	7.94	7.95	8.45	n/a	n/a
5.5	8.68	7.86	7.80	8.22	8.82	n/a
6.0	8.77	7.87	7.85	8.03	8.54	n/a
6.5	8.86	8.04	7.82	7.93	8.34	8.87
7.0	8.98	8.14	7.89	7.96	8.22	8.71
7.5	9.11	8.21	7.87	7.98	8.12	8.57
8.0	9.27	8.36	8.04	8.00	8.13	8.47
8.5	9.42	8.47	8.13	8.04	8.20	8.40
9.0	9.57	8.62	8.27	8.17	8.26	8.35
9.5	9.75	8.77	8.39	8.28	8.32	8.43
10.0	9.94	8.91	8.51	8.33	8.37	8.53

Table E-79 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates increased to 8%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36 month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.40	8.51	9.50	9.06	n/a	n/a
5.0	9.45	8.47	8.29	8.70	n/a	n/a
5.5	9.51	8.49	8.27	8.47	9.00	n/a
6.0	9.61	8.51	8.22	8.29	8.73	n/a
6.5	9.69	8.59	8.20	8.23	8.54	9.03
7.0	9.84	8.68	8.29	8.26	8.44	8.68
7.5	9.85	8.76	8.37	8.28	8.34	8.78
8.0	10.13	8.92	8.43	8.30	8.38	8.65
8.5	10.28	9.04	8.55	8.37	8.45	8.59
9.0	10.43	9.20	8.69	8.49	8.51	8.54
9.5	10.64	9.34	8.80	8.61	8.57	8.65
10.0	10.82	9.51	8.93	8.71	8.62	8.76

Table E-80 Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates increased to 9%.

Enrichment wt% U^{235}	12 month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30 month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.76	9.19	9.36	9.03	n/a	n/a
5.0	9.81	8.13	9.13	9.66	n/a	n/a
5.5	9.90	8.17	8.11	9.43	9.04	n/a
6.0	9.01	8.21	9.08	9.25	8.78	n/a
6.5	9.13	8.31	9.07	9.19	9.60	9.13
7.0	9.30	8.43	9.19	9.25	9.50	9.00
7.5	9.44	9.53	9.28	9.29	9.41	8.89
8.0	9.64	9.71	9.38	9.34	9.45	8.81
8.5	9.83	9.86	9.50	9.39	9.56	8.78
9.0	10.02	9.05	9.68	8.57	9.66	8.72
9.5	10.25	9.24	9.84	8.73	9.75	8.84
10.0	10.49	9.42	9.00	8.87	9.82	8.99

Table E.81 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates increased to 9%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30 month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.57	9.88	9.66	9.24	n/a	n/a
5.0	9.84	9.66	9.47	8.90	n/a	n/a
5.5	9.72	9.70	9.48	8.69	9.22	n/a
6.0	9.85	9.74	9.46	8.61	8.88	n/a
6.5	9.96	9.86	9.46	8.46	8.81	9.29
7.0	10.15	8.97	9.59	8.55	8.71	9.17
7.5	10.29	9.07	9.68	8.59	8.63	9.06
8.0	10.51	9.28	9.77	8.63	8.71	8.86
8.5	10.71	9.44	9.94	8.73	8.82	8.84
9.0	10.89	9.64	9.11	8.90	8.91	8.80
9.5	11.15	9.82	9.26	9.06	9.00	9.07
10.0	11.38	10.04	9.43	9.19	9.07	9.22

Table E-82 Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates increased to 10%.

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.94	9.38	9.54	9.21	n/a	n/a
5.0	9.02	9.32	9.32	9.87	n/a	n/a
5.5	9.13	9.40	9.33	9.86	9.27	n/a
6.0	9.27	9.45	9.33	9.49	9.04	n/a
6.5	9.42	9.59	9.34	9.44	9.69	9.41
7.0	9.62	9.74	9.48	9.55	9.80	9.31
7.5	9.60	9.87	9.62	9.92	9.72	9.22
8.0	10.05	9.10	9.78	9.70	9.90	9.17
8.5	10.28	9.29	9.91	9.79	9.95	9.13
9.0	10.52	9.52	9.14	9.01	9.03	9.11
9.5	10.91	9.76	9.34	9.21	9.22	9.29
10.0	11.10	9.98	9.54	9.40	9.32	9.80

Table E-83 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates increased to 10%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.75	8.86	8.66	9.43	n/a	n/a
5.0	9.85	8.86	8.66	9.11	n/a	n/a
5.5	9.95	8.93	8.70	8.91	9.45	n/a
6.0	10.12	8.95	8.70	8.75	9.23	n/a
6.5	10.29	9.14	8.71	8.75	9.09	9.87
7.0	10.46	9.29	8.86	8.85	9.01	9.48
7.5	10.65	9.42	9.03	8.92	8.94	9.40
8.0	10.83	9.69	9.19	8.99	9.07	9.34
8.5	11.18	9.87	9.35	9.13	9.22	9.31
9.0	11.40	10.12	9.57	9.36	9.35	9.29
9.5	11.73	10.36	9.77	9.55	9.47	9.53
10.0	12.02	10.83	9.96	9.73	9.57	9.73

Table E-84 Fuel cycle costs for plants with 15-day outage for the first 5 years with fuel purchase interest rates increased to 12%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42-month Fuel Cycle Cost mills/kWhr$_e$
4.5	9.33	9.74	9.63	9.91	n/a	n/a
5.0	9.46	8.74	8.73	9.33	n/a	n/a
5.5	9.63	8.89	8.81	9.15	9.76	n/a
6.0	9.85	9.00	8.87	9.02	9.59	n/a
6.5	10.07	9.21	8.93	9.02	9.48	10.00
7.0	10.37	9.45	9.16	9.22	9.45	9.99
7.5	10.63	9.65	9.39	9.37	9.41	9.87
8.0	11.00	10.00	9.59	9.61	9.58	9.97
8.5	11.34	10.27	9.84	9.85	9.85	9.98
9.0	11.68	10.62	10.19	10.02	10.08	9.99
9.5	12.13	11.00	10.51	10.34	10.30	10.31
10.0	12.58	11.33	10.81	10.63	10.48	10.66

Table E-85 Fuel cycle costs for plants with 30-day outage for the first 5 years with fuel purchase interest rates increased to 12%

Enrichment wt% U^{235}	12-month Fuel Cycle Cost mills/kWhr$_e$	18-month Fuel Cycle Cost mills/kWhr$_e$	24-month Fuel Cycle Cost mills/kWhr$_e$	30-month Fuel Cycle Cost mills/kWhr$_e$	36-month Fuel Cycle Cost mills/kWhr$_e$	42 month Fuel Cycle Cost mills/kWhr$_e$
4.5	10.13	9.23	9.24	9.82	n/a	n/a
5.0	10.30	9.29	9.07	9.56	n/a	n/a
5.5	10.46	9.42	9.16	9.40	9.94	n/a
6.0	10.71	9.54	9.25	9.27	9.79	n/a
6.5	10.92	9.79	9.30	9.34	9.69	10.17
7.0	11.24	10.00	9.58	9.53	9.66	10.19
7.5	11.50	10.20	9.60	9.68	9.82	10.14
8.0	11.92	10.69	10.00	9.91	9.86	10.14
8.5	12.28	10.86	10.32	10.03	10.12	10.19
9.0	12.62	11.27	10.65	10.38	10.35	10.17
9.5	13.12	11.62	10.95	10.69	10.55	10.57
10.0	13.57	12.05	11.28	10.97	10.73	10.61

Table E-86 Minimum enrichments for the 18, 24, and 30-month fuel cycle cost trendlines with varying fuel purchase interest rates.

Fuel Purchase Interest Rate	15-day outage			30-day outage		
	18-month wt% U^{235}	24-month wt% U^{235}	30-month wt% U^{235}	18-month wt% U^{235}	24-month wt% U^{235}	30-month wt% U^{235}
5%	6.60	7.73	9.31	6.35	7.62	9.27
6%	6.01	7.34	9.06	5.79	7.19	7.99
7%	5.43	6.61	7.79	5.22	6.73	7.71
8%	4.89	6.47	7.51	4.70	6.27	7.41
9%	4.42	5.86	7.21	4.27	5.83	7.19
10%	4.02	5.64	6.91	3.82	5.41	6.78
12%	3.45	4.94	6.33	3.46	4.70	6.19

LIST OF REFERENCES

1. J. B. Briggs, International Handbook of Evaluated Criticality Safety Benchmark Experiments, Nuclear Energy Agency, Nuclear Science Committee, Organization for Economic Co-Operation and Development, NEA/NSC/DOC(95)03, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID, September 2001 Edition

2. World Nuclear Association, http://www.world-nuclear.org/info/inf23.htm, accessed June 2002

3. Robert G. Cochran and Nicholas Tsoulfanidis, The Nuclear Fuel Cycle Analysis and Management, American Nuclear Society, LaGrange Park, IL, 1990

4. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/materials/fuel-cycle-fac/location-maj-facilities.html#2, accessed June 2002

5. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/materials/fuel-cycle-fac/ur-conversion.html, accessed June 2002

6. Converdyn, http://www.converdyn.com/dfcp.html, accessed June 2002

7. U.S. Nuclear Regulatory Commission, http://www.usec.com/v2001_02/HTML/Facilities_PaducahOverview.asp accessed June 2002.

8. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/gaseous-diffusion.html, accessed June 2002

9. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/materials/fuel-cycle-fac/usecfacility.html, accessed June 2002

10. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/materials/fuel-cycle-fac/lesfacility.html#regulation, accessed 2002

11. U.S. Environmental Protection Agency, http://www.epa.gov/fedrgstr/EPA-IMPACT/2002/January/Day-16/i1089.htm, accessed June 2002

12. U.S. Environmental Protection Agency, http://www.epa.gov/fedrgstr/EPA-IMPACT/2003/January/Day-07/i264.htm, accessed June 2002

13. N. L. Ranek and F. A. Monette, Evaluation of UF_6-to-UO_2 Conversion Capability at Commercial Nuclear Fuel Fabrication Facilities. Argonne National Laboratory, Argonne, IL, May 2001

14. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/waste/spent-fuel-storage/designs.html, accessed June 2002

15. U.S. Nuclear Regulatory Commission, http://www.nrc.gov/waste/spent-fuel-storage/locations.html, accessed June 2002

16. RSICC Computer Code Collection. MCNP4C2 Monte Carlo N-Particle Transport Code System, document CCC-701, Oak Ridge National Laboratory, Oak Ridge, TN, June 2001

17. R. W. Tayloe Jr., Nuclear Criticality Safety Study for Increased Enrichment Limit in 2 1/2 Ton (30B) UF_6 Cylinders, POEF-T-3597, Battelle, Columbus, Ohio, October 1992

18. Dr. Phillip E. McDonald, Advanced Proliferation Resistant, Lower Cost, Uranium-Thorium Dioxide Fuels For Light Water Reactors, NERI Project 99-1053. Idaho National Engineering and Environmental Laboratory. Idaho Falls, ID, December 2002

19. U.S. Nuclear Regulatory Commission, ftp://ftp.emwebwin.com/pub/downloads/doc5/1016206.PDF, accessed December 2002

20. Vogtle Electric Generating Plant Updated Final Safety Analysis Report, Southern Nuclear Operating Company, Birmingham, AL, November 2001

21. Malte Edenius and Bengt H. Forssen, CASMO-3, A Fuel Assembly Burnup Program User's Manual, Studsvik/NFA-89/3, Studsvik of America, Inc., Newton, MA, June 1993

22. Erwin Kreyszig, Advanced Engineering Mathematics, 7th edition, John Wiley & Sons, Inc., New York, 1993

23. William H. Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, Numerical Recipes in C in the Art of Scientific Computing, Cambridge University Press Cambridge, U.K., 1988

24. The Ux Consulting Company, LLC, http://www.uxc.com/review/uxc_prices.html, accessed January 2003

25. The Ux Consulting Company, LLC, http://www.uxc.com/review/uxc_g_conv-price.html, accessed January 2003

26 The Ux Consulting Company, LLC, http://www.uxc.com/review/uxc_g_swu-price.html, accessed January 2003

27 Office of Civilian Radioactive Waste Management, http://www.ocrwm.doe.gov/pm/pdf/feendr1.pdf, accessed January 2003

28 Roadtechs, LLC, http://www.roadwhore.com/nukeout.htm, accessed January 2003

29 The Ux Consulting Company, LLC, http://www.uxc.com/review/uxc_prices_mth-end.html, accessed January 2003

30 Board of Governors of the Federal Reserve System, http://www.federalreserve.gov/releases/h15/data.htm, accessed March 2004

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